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PRESIDENT'S MESSAGE

Frank F. Groseclose

In my last message to you I would like to express my thanks for the splendid cooperation and support given by our membership, old and new, during the past year. Our JOURNAL space is too valuable for extended messages by "fade-away" presidents.

There are three special topics I would like to touch briefly. First, the phenomenal growth of Industrial Engineering in the past decade has pointed to the growing importance of our field and is a tribute to all those who have had a part in this growth. Although this growth has completely eclipsed the other fields, it has been steady and sound. I am proud of the fact the AIIE has been an important factor in this growth. The primary reason for these results has been the rigidness of our membership requirements.

This relatively rigid path laid out by our founders, under the early leadership of Wyllys G. Stanton, has gained international recognition by outstanding engineers and their societies.

My second topic grows out of some of the dangers that lurk in the shadows of our remarkable progress. Although the Industrial Engineering curriculum was recognized by ECPD in the first days of its accrediting program, many schools were slow to recognize the importance of this field and some schools have opposed having such a curriculum. The demands from industry employers have converted some of our better schools to the point of including good curricula. On the other hand, this same demand has created undesirable course offerings at less qualified schools resulting in degrees of questionable value. This resulting shortage of first-class I.E. graduates has also encouraged the employment of too many pseudo-engineers who tend to

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Editorial Comments--

Industrial Engineering At The Crossroads

By Robert N. Lehrer, Editor-in-Chief

Associate Professor of Industrial Engineering, Georgia Institute of Technology

Do you ever feel that we've stalled at the cross roads and don't know which way to go? I sure do, even in spite of the many wonderful accomplishments that Industrial Engineers are making every day. We Industrial Engineers seem to want to sit back and glory in our accomplishments instead of broadening our horizons and doing a *more* effective job. Maybe we suffer from smug complacency.

Industrial Engineering had a modest beginning in the 1880's. An engineer named Taylor developed an approach to work-problems that involved the "engineering" method. He recognized the importance of technology, the importance of man as a human, and the importance of man as a mechanism. Taylor's basic concepts could be stated as involving the determination of what *needed* to be accomplished in a work-situation, what *should* be done, what *could* be done, *how* it could be done, and then seeing that it *was* done. The old saw "Plan the Work then Work the Plan" was descriptive of Taylor's approach.

From almost the very beginning, Taylor's concepts were misinterpreted. His "System" was soon called "Scientific" Management, even though it was not scientific in fact. His approach was scientific in principle, and he did strive for scientific understanding of cause and effect. He made use of considerable scientific knowledge from many "disciplines" in the development of principles and the solution of individual problems. But, in his day as in our own, engineers suffered from smug complacency. The Taylor "System" was "borrowed" and exploited. It was said to be scientific, and thus a cure for all ills.

With the exception of the very outstanding work of the Gilbreths, it was not until the 1930's that we were much concerned with abandoning the mechanistic approach to Industrial Engineering. We were so engrossed in empiricism that we tended to forget that theory *does* exist. We were plagued with the efficiency-expert, the speed-up, rate-cuts, and bitter resentments. We attempted to solve our problems by rule-of-thumb and a stubborn insistence that the other guy made mistakes, but not us. We still have not completely abandoned the mechanistic approach in favor of a better theoretical understanding of the nature of our problems as a means of better solving these problems.

Gradually, however, we have been getting into an era of *enlightened* empiricism. We are finally coming to recognize that we aren't always right. We've had to swallow some bitter pills, and question the adequacy of our own concepts, techniques, policies, and results. We are looking to the other disciplines, we are experimenting and researching a bit, we are improving our techniques, policies and results. But, have we gone far enough? I think we need a concentrated "quest for fundamental knowledge" in Industrial Engineering if we are to continue to hold or improve our stature.

You may think I'm an alarmist. But, let me list a few areas where we Industrial Engineers have failed. We have failed in these areas due to smug complacency and lack of effort.

1. HUMAN ENGINEERING—the concept of designing jobs and equipment to suit the needs and abilities of the human—developed by the psychologist and the physiologist.
2. OPERATIONS RESEARCH—the team approach to operational problems with quantitative analysis and the use of theoretical models to explain phenomenon—developed by the physical scientist.
3. HUMANIZED ENGINEERING—the concept of human relations developing out of an industrial environment—developed by personnel specialists, economists, and administrators. It's interesting to note that the I. E. still has a clear field to develop industrial relations that are preventative rather than remedial. The most logical place to improve industrial relations is at the heart of the problem. And that happens to be where the I. E. does his work.
4. QUALITY CONTROL—the concept of statistical evaluation of quality for control purposes—developed by the mathematicians. Some Industrial Engineers have been quick to see the advantages of statistical inference, but many are blind to its importance.
5. PROCEDURE AND SYSTEM ANALYSIS—the concept of information flow, use and control—developed by the office manager.
6. ELECTRONICS FOR NUMERICAL ANALYSIS AND CONTROL—the use of electronic computers to rapidly and automatically gather and analyze data for solving operational problems and helping to control processing and production—developed by the electronics specialist and the mathematician.
7. AUTOMATION—the extension of mechanization to automatic operation of processes by use of functional design of products and processes, development of self-correcting and self-controlling instrumentation, and rapid processing of operational data by electronic calculators—developed by the electronic specialist, and the mathematician.

The above is intended as a partial listing to indicate a few of the areas where Industrial Engineers have failed to be challenged. Not all Industrial Engineers have ignored these areas, but most have. It is a crying shame that we have defaulted so many times. Worse yet—it looks as though we will continue to default in the future.

Why do I say that we Industrial Engineers are likely to continue to default and ignore the development possibilities that we are rightly entitled to? Let me list a few typical characteristics of Industrial Engineers that explain why we are inclined to default.

1. PREOCCUPATION WITH MANAGEMENT-AS-A-GOAL. Too many Industrial Engineers regard their engineering work only as a means to an end. They aspire to be "management," and so they are blind to the many opportunities for high level work within the field of Industrial Engineering. Many companies have policies which discourage full development of professional Industrial Engineering. They have encouraged using Industrial Engineering activities as a management training-ground. Management aspirations are quite noble—but why should we over do it to our own detriment? Industrial Engineers should be encouraged in their professional development as Industrial Engineers. The organizational position of Industrial Engineering should provide ample opportunity for development within our own field. The service that can be provided by top-notch Industrial Engineering certainly does justify high level organizational positions for good Industrial Engineers within almost every company.
2. PREOCCUPATION WITH MANAGEMENT ENGINEERING RATHER THAN ENGINEERING *FOR* MANAGEMENT. The Industrial Engineer can best serve when he retains his identity as a staff specialist—as an engineer *for* management. The Industrial Engineer usually has managerial ability, but he loses his full potency when he takes on line responsibilities.
3. RULE-OF-THUMB IS ADEQUATE. The Industrial Engineer actually seems to fear theory. Maybe this is due to our training and daily reliance on techniques and gimicks. We do need better solutions to our problems. The rule-of-thumb procedures are proving to be inadequate. A fuller theoretical development of the basic Industrial Engineering concepts will enable us to do a more effective job—and to better serve by better solving our Industrial Engineering problems.
4. MECHANISTIC APPROACH TO OUR DAILY PROBLEMS. Most all engineers tend to be mechanistic. We rely on formula, technique and empirical knowledge. This is all fine within limits. It is extremely dangerous in Industrial Engineerng work, for human values must be considered as an integral and vital part of nearly every problem. We have many lessons to learn and relearn from the social sciences.
5. LET'S GET AWAY FROM ENGINEERING. Why do so many Industrial Engineers want to forget their engineering? We are engineers first of all—but engineers with more than other engineers. Technology, when properly integrated with the social and management "sciences" in the form of Industrial Engineering is an extremely potent tool. The application of the physical sciences with the touch of the Industrial Engineer gives technology much more effectiveness.

(Continued on Page 18)

Work Sampling Applications

By D. G. Malcolm[1] and L. L. Sammet[2]

Work sampling is an increasingly popular method for measuring certain types of plant and office activity. It is a means of estimating the proportion of time spent by individuals or machines in a given category of activity. Since "activity" may be thought of as work in the broad sense and the estimates are based on sample observations, with statistical criteria for testing the accuracy of the results, the term "work sampling" seems appropriate. This is by way of explaining and promoting this relatively new and broader title for a method generally referred to in the literature[3] of the field as the "ratio-delay" method.

This technique was introduced by a British statistician (1)[4] as a means of determining the delay allowances to be used in time-study standards. Recent practice has considerably broadened its use. For example, the work-sampling procedure has been used in determining the following:

1. Machine utilization percentages
2. Operator utilization percentages
3. Traffic flow in elevators
4. Standards for indirect labor
5. Efficiency of indirect labor
6. Departmental activity index
7. Distribution of material handling time
8. Down time percentages for assembly lines
9. Best opportunities for savings in a work simplification program
10. Percentage of clerical time in "make ready," "do," and "put away" categories
11. Actual duties performed versus duties assigned or specified.

This increasing use of work-sampling techniques has resulted from the substantial savings it frequently offers in the labor of data collection, the possibility of applying objective tests of reliability to the measurements obtained, and the flexibility of the method when applied to different work situations.

The purpose of this paper is to present new applications and variations of the work-sampling technique as follows:

1. A method for determining element times and production unit times
2. A study of the flow pattern in materials handling
3. Studies of jobs involving a "team" or "gang" method of operation.

In a subsequent article in this Journal, the authors will discuss statistical criteria for describing the reliability of certain types of work-sampling estimates.

The Nature of Work-Sampling Studies

The work-sampling process can be visualized most easily by examples, such as the following drawn by the authors from recent studies of operations in fruit packing houses in California.[5]

Estimating proportions of "delay" and "working" time

One of the operations studied was packing fruit into a wooden box. Suppose our only objective is to obtain an estimate of the proportions of net "working" and "delay" time of several workers engaged in this activity in a given plant. The procedure would be as follows:

1. Design a form similar to Figure 1
2. Observe each worker at repeated and relatively uniform intervals; obtain a series of instantaneous or "flash" observations on each worker
3. For each observation, enter a tally mark in the appropriate column, that is, either "working" or "not working." (In this example, we have 200 separate observations on each of 10 packers, a total of 2,000 observations)

Sheet 1 of 3 — WORK SAMPLING STUDY — Observer: E.S.V

Plant B
Date 7-15-50

Job	No.	WORKING a/	NOT WORKING a/
Packer	101	177	23
"	102	180	20
"	103	179	21
"	104	182	18
"	105	182	18
"	106	178	22
"	107	181	19
"	108	183	17
"	109	178	22
"	110	180	20
Total		1800	2000

FIGURE 1. WORK-SAMPLING DATA SHEET.
a/ Totals shown are the sum of observations from three sheets.

4. The percentage of "working" time is then given by the ratio (1,800/2,000) 100 = 90 per cent of the total packer time; similarly, "delay" time is 10 per cent.[6]

Estimating element and production unit times

If the work-sampling data include a record of elapsed time and production during the observation period, the percentage of productive work time can be used to estimate the net unit production time. This process can be extended to obtain a breakdown of the "working" and "nonworking" categories. Figure 2 shows a typical form used in such a study. Note that the elements are similar to those of a time study, with "break points" between elements carefully defined as in time-study work. The totals extended at the right of Figure 2 represent the totals from several such sheets used during the study.

A summary and analysis of the work-sampling data shown in Figure 2 are given in Table 1. This table shows the percentage time distribution and the estimated element and unit production times for each classification observed. These results are similar to the standard times that would be derived from time studies of this operation.

No attempt at "rating" or "leveling" is indicated in the above example since the objective was to obtain a typical time for the operation as actually performed rather than to determine a standard in relation to an expected level of performance. The refinement of performance rating could be added to this type of study by ruling the data sheet into performance-level columns or by rating periodically as the observations are made. Gustat reports the use of mark-sensing IBM cards for such ratings (16).

While there may not be many industrial operations of this type, the procedures are adaptable and in many situa-

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[2]Cooperative Agent, California Agricultural Experiment Station and the Agricultural Marketing Service, U. S. Department of Agriculture, Berkeley, California.

[3]The term "work sampling" first appeared in the literature in reference (13).

[4]Numbers in parentheses refer to bibliography at the end of the paper.

[5] This work was performed as part of a study of efficiency in the operation of deciduous fruit packing houses made by the Bureau of Agricultural Economics, U. S. Department of Agriculture, and the California Agricultural Experiment Station under authority of the Research and Marketing Act of 1946.

[6]Procedures for testing the reliability error of work-sampling proportions are presented in several of the references to this paper. See, for example, reference (11) or a subsequent article to be published by the authors in this Journal.

WORK SAMPLING STUDY

Plant X Fruit Co. Date 10/31/51 Observer B.F.

JOB Title & no. of workers	Breakdown	Totals a/
Packer - 56 workers	Get bunch	413
	Trim and place in pot	940
	Finish pack	83
	Get and dispose of field lug	71
	Get and number packing box	73
	Get and place liners	228
	Dispose of packed box	52
	Break for lots	115
	Wait (miscellaneous delay)	34
	Total	2009

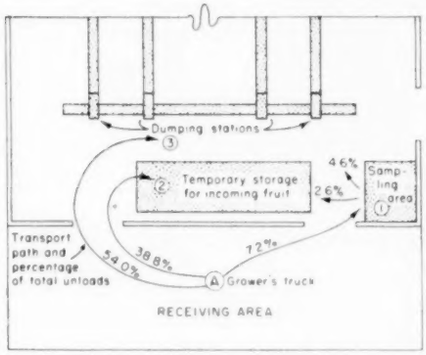
FIGURE 2. SAMPLE WORK SHEET FOR COLLECTING OBSERVATIONS ON ELEMENTS OF THE JOB OF GRAPE PACKING.
a/ Totals shown are the sum of observations from three sheets.

tions should yield more representative work measurements than are possible by time-study methods.

The reliability of estimates of unit production time, or of element times obtained in a given study, depends on the reliability of the sampling proportions. Any desired level of reliability can be attained by obtaining a sufficiently large number of observations.

Flow pattern in materials handling

Estimates of the flow pattern may be useful in studies of materials handling. The use of work-sampling techniques to obtain such data may be illustrated with studies of the receipt of incoming fruit at a packing house. In the example given in Figure 3, palletized loads of incoming fruit were transported from a highway truck to one of three locations as indicated. The study was designed to provide a quantitative description of this work. On each tour of the observation route, the observer made instantaneous observations in which each fork truck was classified as "working" or "not working." The "working" observations were also subclassified for load carried and transport path followed. From these observations the proportion of working time expended in each transport path was computed. These proportions were then adjusted for differences in transport time per trip, using as weighting factors estimates of transport time per trip derived from time studies of the trucking operations. The adjusted proportions, indicating the proportion of unloads in each transport path, are given in Figure 3. A simpler procedure, using the relative distances in each transport path as weights, probably would be satisfactory in many situations.



Studies of "team" or "gang" operations

Figure 3. Lay-out of packing-house receiving area, with transport paths for unloading growers' trucks and percentage of total unloads in each path.

Work sampling of "team" jobs may be illustrated with a study of stacking packed boxes of grapes in a cold storage plant. In this operation, lidded boxes of fresh grapes of approximately 32 pounds gross weight each were placed manually in storage stacks 18 boxes high. The job elements involved are described in Table 2.

The frequent and irregular shifts in job elements, and joint work by two or more crewmen on some elements, made this operation poorly adapted to time-study or production-study techniques. A work-sampling study was devised, which gave the proportional distribution of crew time to the various work elements indicated in Table 2. This table also gives the proportion of total time expended in "miscellaneous delays" and in "system" delays occurring in the team operations required in stacking boxes in the upper tiers. The element times given in Table 2 are computed from the estimated amount of crew time expended in each element and the observed number of work units completed.

While the operation summarized in Table 2 is relatively simple, the method may easily be applied to more complex situations. The technique should be especially useful in detecting unbalanced work loads in a given crew organization.

TABLE 1
Summary of a Work Sampling Study of Grape Packing

Elements	Total observations		Per cent of working observations		Per cent of total observations		Time per box* man-minutes	
Get bunch	413		22.20				.65	
Trim and place in box	940		50.54				1.47	
Finish pack	83		4.46				.13	
Total trim and pack		1,436		77.20				2.25
Get and dispose of field lug	71		3.82				.11	
Get and number box	73		3.92				.11	
Get and place liners	228		12.26				.36	
Dispose of packed box	52		2.80				.08	
Total (not trim and pack)		424		22.80				.66
Total working		1,860		100.00		92.58		2.91
Delay (break for lots)	115				5.73		.18	
Delay (other)	34				1.69		.05	
Total delay		149				7.42		.23
Total work and delay		2,009				100.00		3.14

*Total man-hours worked—392; boxes packed—7,488.

Statistical Tests of Reliability of Work-Sampling Measurements

Although statistical tests of reliability and procedures for analyzing the results of work-sampling measurements are not discussed in detail in this paper, a brief reference to this problem is necessary to a consideration of observation procedures. Three aspects of the problem of statistical tests and analysis are noted as fol-

TABLE 2
Summary of Work-Sampling Data and Estimated Element Times for Manually Stacking Packed Grape Boxes in Cold Storage, Using a 3-Man Crew

Element	Number of observations	Work sampling proportions	Estimated total time per element[1]	Number of units handled	Estimated time per element per unit
		per cent	man-minutes	boxes	minutes man-
Align each box in first tier	73	6.27	11.85	60	0.198
Stack lower 11 tiers of boxes	319	27.40	51.80	425	0.122
Hand box up for upper 7 tiers	118	10.14	19.16	233	0.082
Stack upper 7 tiers	112	9.61	18.18	233	0.078
Place and remove platform	76	6.53	12.34	233	0.053
Delayed by other workers	30	2.58	4.87	658	0.007
Hand truck stacks of boxes from conveyor	128	11.00	20.79	658	0.003
Get and place wood strip	121	10.40	19.65	——	——
Write warehouse tag; check lot	84	7.22	13.64	——	——
Total working	1,061	91.15	172.28	658	0.262
Wait	103	8.85	16.72	658	0.025
Total work and wait	1,164	100.00	189.00	658	0.287

[1]Based on observed crew time of 63 minutes (equivalent to 189 man-minutes).

lows:

1. Tests of reliability of the proportions derived from a given study.[7]
2. Tests of homogeneity of results from a series of studies of a given job over a time period, or when performed by different workers or under different working conditions; or analysis of variations observed in such studies.
3. Evaluation of the significance of work-sampling results as "forecasts." A correct appreciation of the applicability and limitations of statistical tests with respect to work-sampling results and the design of observation procedures rests on careful distinction between these categories.

In the first category, we are dealing with the reliability of the proportions observed in a particular work-sampling observation period. If the successive, individual observations obtained in such a study closely approximate unbiased, random, and independent observations, simple tests of the reliability of the proportions *derived from this particular study* can be made on the basis of an approximation to the binomial theory.

Tests in the second category relate to the analysis of the results of a *series* of work-sampling studies of a given job. The reliability of the proportions obtained in each of such studies may be tested as indicated above. Statements regarding the reliability of estimates derived from the series of studies, however, require further analysis. This may involve analysis of variance, regression analysis, or other procedures to test the homogeneity of the group of studies or to measure variation in the results in relation to time, or with respect to some measured variation in the work situation. If such tests demonstrate homegeneity with regard to the separate studies, the data may be pooled. Depending on the circumstances, this may involve pooling the *observations* from the entire series of studies, or pooling the *results* (for example, unit production times) of the separate studies. If time trends, or other systematic variations are indicated, the nature of these relationships can be estimated.

In regard to the third category, work-sampling procedures have a similarity to all methods of measurement. The data from any method of measurement provide a basis for probability statements concerning predictions of future events —that is, "forecasting" — *only* if the population from which the estimates are drawn extends unchanged through the period of prediction. In the absence of knowledge of the future population, however, tests which indicate a high degree of stability in the relationships being estimated support their use as "representative" data, or as a basis for forecasting.

Procedures in Obtaining Work-Sampling Observations

Regardless of the analytical procedure applied to work-sampling results, the presumption that single observations in a given study are unbiased, random, and independent is desirable. Although procedures that yield this type of observation precisely do not seem practicable, the exercise of reasonable precautions in collecting data should yield observations that closely approximate the ideal.

As a first step, the work at each station should be studied and a written job description prepared. The observer thus becomes familiar with the details of each job so that rapid and consistent classification of each observation can be made. This step becomes more important with the finer breakdown of a given job. If element times are to be measured, descriptions of the work content of each element similar to time-study element descriptions should be made and studied by the observer prior to each work-sampling study. This will insure maximum consistency in studies made over a period of time or made by different observers and is a vital precaution if such studies are to be consolidated into single summaries.

If the study involves a complete plant tour on each round of observations, a schematic drawing of the plant should be made, showing the observation route. Several preliminary tours over this route should be made before starting the actual study. In some situations, however, a complete plant circuit on each round of observations requires the observer to spend a disproportionate amount of time in nonproductive travel between stations. More economical use of the observer's time, with satisfactory work-sampling results, may be obtained in such cases by dividing the plant into zones. The work in the various zones may be sampled successively by a single observer or simultaneously by several observers.

All observations should be made as instantaneously as possible. This is necessary to eliminate any tendency to anticipate what the work status should be or what the observer might subconsciously prefer it to be. Ideally, each observation should be made as though it were obtained through a momentarily open camera shutter.

The question of what to do about long delays will arise. The procedure followed should recognize that work sampling is essentially a sampling of the observed time period to estimate the proportion of time spent in each category of activity. All possible events should have an equal chance—commensurate with the length of the event—of being observed. Thus, it is consistent with a random sampling procedure to record the same delay, if it is a long one, on successive trips. This procedure will result in a more reliable estimate of the delay time than procedures described in the literature, which involve scheduling the observations so that the time per trip is somewhat longer than the longest delay, or counting the delay only once if it extends into a subsequent round of observations. Delays which stop an entire section of a plant, or which delay an entire crew, may be handled by continuing the work sampling throughout the delay, or by a separate clock accounting of such delays. In cases involving numerous jobs and subcategories, it may be desirable to maintain a time log of the beginning and end of each observation circuit. This log may also be used to record suspensions of the work sampling during long breaks, such as lunch periods, rest periods, or equipment failure.

When studies are made by a zoning procedure, or in studies of team operations, a nearly continuous contact with the work crew may result. This introduces special difficulties in obtaining unbiased observations. Several helpful techniques can be used. For example, the observer may follow a deliberate practice of "detaching" his attention momentarily from the work group after each round of observations, returning to each new round with the flash observation described

(Continued to Page 23)

[7] By "a given study" we have in mind the procurement of several hundred observations, closely spaced over a continuous and relatively short time period. The repetition of such individual studies over time, or in relation to known variations in the work situation—for example, variations in crew organization, in work method, or in other working conditions—is referred to in this paper as a "series of studies."

Plant Investment and Survey Results

By Edward C. Keachie
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A hundred years ago the promoters of the "Great Eastern," the world's largest ship, promised investors a 40% return on their money—yet she was financed and went through bankruptcy twice before setting out to sea with a single paying passenger. Some of the reasons given to encourage her investors sound familiar to present-day industrial engineers—with her paddle, screw, and sails she could travel around the world without refueling, thereby saving time and expense—"she was so big that she had inherent advantages over ordinary ships."

Here, then, near the beginning of the age of the modern engineer, stood a classic example of man's growing yen to put capital into equipment today, for a larger return tomorrow. In fact, we are said to be making longer commitments every year; that, for example, the trend to automation increasingly weights capital costs as against labor costs and other costs of production. The real significance of this, of course, is that we are increasingly spending money for labor before we even begin to make and sell the product, because we are buying, in advance, the labor that produces capital equipment, in preference to buying, later, labor to operate that equipment as we produce and get income from it.

If plant investment is growing in relative importance in engineering analysis, it deserves more than ever the best thinking of those who are responsible for it. Even beyond that, the absolute status of the investment decision has been greatly raised in the last ten years, with current national spending for plant and equipment running over 25 billion dollars a year. Finally, since capital goods spending encourages consumer spending which in turn encourages more capital spending, it is of key importance as a feedback controller in the business cycle. For all these reasons, then, it seems difficult to overstate the importance of the investment analysis in industrial engineering and management. But the big question is—how good a job is actually being done in making the analyses and the final decisions?

SURVEY FINDINGS—In general

One way to assess the job being done is to compare actual practice in plant spending analysis with accepted theory found in the literature. The authors have done field checking with interesting results, albeit limited mainly to moderate sized firms in the San Francisco-Oakland Bay Area. The results are quite comparable with the few reported data about firms in other parts of the country, with some special implications for moderate-sized firms of 50-500 employees.

A mail survey of the west coast had shown that some of those making decisions on plant investment not only did not use the theory available, but did not even know it existed. It was obvious that individual face-to-face interviews would be necessary to find out what was really being done. Likewise, where sizeable firms were involved, with people on different levels of authority progressively passing on investment plans, it was desirable to interview people at the several levels to get the full picture. Partly this was due to obvious limitations of time and scope in talking to one person, but partly also to the well-known fact that actual practice differs so often from the clear crisp statements of the procedure manual. A familiar example is the "strict rule" limiting approvals of any level of supervision, say the works manager, to, say, $1500—yet who has not seen the piece-meal smuggling in of bigger jobs, $5000 or more in such cases, with more or less elaborate covering paperwork, depending on the circumstances, procedural and personal.

Most respondents seemed to have some acquaintance with the theory of engineering investment, including the use of the time value of money and interest rates. But it was more honored in the breach than the observance—"Too complicated"—"Not justified in our business" (some day maybe that one will be laid out for good by I.E.'s—we fondly hope!) "No time" (how much time does it take to make the money he loses on poor investment decisions?) and so forth. However, all such excuses are plausible, and, fortunately or not, any one of them may be true at a given moment.

SURVEY FINDINGS—In particular

Establishing Benchmarks

In teaching engineering economy one is naturally interested in the way former students as well as others are actually handling the problems of what is done, how and why it is done, and who does it. The relation of theory to practice is worthy of continuous observation and study. There is of course no real conflict between theory and practice—sometimes we may not use our theory and sometimes we may be hard put to explain practice in terms of theory, but the relationship is always there; we may need to dig to find it, in order to evaluate action correctly. Take for example the idea of "sunk" costs, so often mishandled in practice. When equipment is obsolete but not written off, the human tendency is to keep it operating, and not recognize that the entire investment is really dissipated or sunk. We should adapt our practice to our theory and recognize in the words of one of our survey respondents:

> "It's cheaper to keep it idle than to use it, and it's cheaper to throw it away than to keep it idle!"

To help him follow his own advice he lists the "Design Age" in addition to the usual "Actual Age" figure on the equipment data sheets. This points up real obsolescence while perhaps even playing down the accountant's accrued depreciation.

While the accountant's figures may be valid and useful for purposes such as charging production for current depreciation and conforming to tax law write-off provisions, they are usually inadequate for engineering investment analysis. The reason is the basic one that our analysis must stand or fall on our estimate of future costs, both capital and operating, as well as on related estimates of volume and income. This points up our opening remarks on the importance of the forward-looking investment analysis, on "prospects for profit" rather than past or present profits.

Even more significant is the reference to *increasing* mechanization as distinguished from mere replacement of existing facilities. If, for example, by automation, we increase our rate of capital spending and thus buy more of someone else's past labor and relatively less of our own future labor, we are increasing our fixed costs in relation to variable costs.

The implications for investment analysis are clearly significant but they need not be startling. In brief, a premium is put on correct prediction of costs and returns, as well as on correct methods of analysis. At the same time the problem is made more difficult because the very nature of the data is changing; the new equipment, costs, and volumes are different both qualitatively and quantitatively from the old. Old rates of depreciation, for example, may or may not be valid indicators of the new. In sum, a look at the past will always be helpful, but ever more diligence will be needed to analyze the newer investments. If profits are to be maximized or even made at all, the false crutches of past practice and the blinders of past figures must not be allowed to disrupt our analysis of present facts and future probabilities; and the greatest premium of all will be put on the use of correct methods of analysis in making the investment decision.

Methods and Formulas

The "Pay-out Period" or "pay-off" was the most used rule or formula for judging the excellence of investments. The typical reasons given for its use were: simplicity, ease of getting data and making computations, and ease with

give the number of years in which capital is recovered. As commonly used, no charge or allowance is made for depre- which projects can be compared. To use this method, the investment amount is divided by the annual net "profits" to ciation, interest, or taxes in arriving at the profit.

The only other formula used in practice in companies contacted by Gonzales (3) was the rate of return method, familiar to most of us as the text-book standard. Here the net annual profits are divided by the investment to give an annual rate of return, comparable to figuring the return on stocks and bonds. Depreciation is charged, preferably by the sinking fund method although the survey showed the straight-line method often used. Table I shows what appears to be

TABLE I

Formulas Used and Attractiveness of Cost-Savings Projects Required by Companies Studied

COMPANY	FORMULA	LIMIT FOR COST-SAVING PROJECTS (Upper limit for time) (lower limit for %)
A	Pay-out	2 years
B	Rate of return	60%
C	Rate of return	50%
	Pay-out	2 years
D	Rate of return	25%
E	Pay-out	2 years
F	Pay-out	3 years
G	Pay-out	5 years
H	Pay-out	2 years
I	Pay-out	3 years
J	Pay-out	1 year
K	Pay-out	1 year
L	Rate of return	40%
	Pay-out	3 years
M	Pay-out	3* years

* This company requires for example that a cost-saving project of $10,000 should pay-out in three years and should eliminate at least one man.

a startling picture of "conservatism" in the requirements of companies for short payout periods and high returns. It also shows the predominance of the "pay-off" method and the use by some companies of both methods as a check on one another. The emphasis on cost savings projects rather than expansion projects helps to focus this question of method; major promotions might be allowed longer amortization times.

Variation in actual method of application of formulas was found between companies, so that the quotations of Table I are not always strictly comparable. While we may criticize this on the grounds of faulty application of theory, the companies actually have the chance at least, to make final conclusions in view of these variations, and so actually make equally valid analyses of their investment problems.

As a whole, the interpretation of the rate of return in industry is well established. This, however, differs slightly from the standard concept by the method in which the depreciation charge is calculated. In practice, depreciation is commonly figured on the simple straight-line basis which understates the rate of return. The correct way of calculating the depreciation for the rate of return is by the sinking fund method. The required rate of interest can be found in either of two valid ways, as will be shown in a later paragraph.

Three companies figure their pay-off period on gross income before depreciation and taxes. Income tax reduces considerably the profits, and by not taking it into consideration, the resulting pay-off periods are much shorter than what they might be. This is one reason why the required pay-offs vary from one company to another. A major purpose of measuring capital earnings is to help management in listing all of its proposals in the order of their profitableness, so that the available funds will be spent only on those projects that will bring more profits to the company than any of the proposals left out. There are several formulas available that can be used as yard-sticks, but they vary in the continuity and relativity of their scales.

The "total cost" (5) and the "MAPI" (6) are types of one scale yardsticks. These formulas can determine whether or not an expenditure for savings meets the minimum requirement of the company, but can not rank them in the order of their profitability. This means that the company has to adjust its financial budget to meet the physical budget or recalculate their proposals with different minimum requirements. Further, in carrying out the approved proposals, the company will have to use means other than profitability to determine priorities. It can be said, therefore, that these two formulas are deficient as a measure of relative profitability.

The pay-off as a measure of profitability has a continuous scale, but its scale does not give relative propriety of investments when the lives of the different facilities in consideration are not the same. Facilities with longer economic lives tend to show a longer pay-off period, especially when income tax is taken into consideration.

The rate of return as a measure of productivity should be considered as the best available investment yardstick when tangible factors are considered. The minimum rate of return for individual proposals can be adjusted by experience and good business judgment to take care of risks and other intangible factors when final approval is made on project by project basis.

As shown in Table I, the percentages of required return differ from company to company. This is to be expected partly because calculations are not always made on the same basis. Further, the percentage of required return is a factor here, as will be discussed in later paragraphs on the interest rate. Suffice to say now that proposals with "inadequate" rates of return are not reviewed if the company has no funds for them, unless they are "mandatory" for other reasons.

One of the simplest approaches to evaluation of effectiveness of investment formulas is the extent to which they are used in practice. As shown by the results of this survey and the earlier work, the rate of return and the pay-out are the only two formulas extensively used in industry. It is recognized, however, that the now popular pay-out has its limitations, especially on "brick and mortar," expansion of production or production of new products investments. The traditional rate of return, on the other hand, is still used by most companies where the pay-out is not applicable.

The Interest Rate

It would seem that since the interest rate is common to all economy studies, no matter what the particular approach, that there would be some agreement as to the method of obtaining the interest rate best suited for practical application. However, this is not the case; there seem as many approaches as there are authors. In view of the significance of the interest rate used in economy studies and the importance of these studies in general it was deemed that further investigation of the interest rate was necessary (4).

Purpose. To facilitate the study of the interest rate following purposes were established: 1. to compare the two broadest concepts of an interest rate, namely, the interest rate used for discounting future sums of money and the interest rate at which capital earns money; 2. to present the businessman's choice of an interest rate as revealed through investigative interviews; and 3. to find the common meeting-ground between theory and business practice in the selection of an interest rate for engineering economy studies.

Limitations. It was not the intent of the study to delve into the justification for the existence of an interest rate, since this problem has been explored at great length by economists for many years. Rather, the existence of interest was accepted as an accomplished fact. As an additional limitation, the study considered only those rates of interest which may, for the sake of simplicity, be assumed to remain constant for the periods of time commonly under consideration in economy studies. Furthermore, it was concerned with those rates of interest which would be most applicable in the economy studies of manufacturing type industries which are conducting business for the primary purpose of making maximum profits for the owners. (Other than public utilities.)

Results of Interviews. The results of the interest rate survey confirmed the earlier findings, that, for the most part, business firms did not use a rate of return criterion in evaluating investments. Instead they relied on the pay-out period and subjective judgment to yield the relevant decision. Consequently, most of the firms contacted did not use any interest rates in their economy study calculations since the pay-out period calculation does not require one.

The most notable departure from the theoretical or ideal situation was that the economy study of a proposed investment

(Continued on Page 22)

A Multidisciplinary Analysis Of A Problem Of Engineering Cost Estimating: A Case History

The papers presented here deal with a special problem of preparing engineering cost estimates for non-repetitive, large production items from pre-engineering data.

The present work was originally given at the 1953 Spring Meeting of the American Society of Mechanical Engineers in Columbus, Ohio.

The authors wish to acknowledge the significant contributions made by the other five members of the original team, namely Dr. Robert P. Bullock, Department of Sociology, Ohio State University; Dr. W. Bennett Shimp, psychologist, Columbus, Ohio; Prof. C. H. Hollister, chairman, Department of Engineering Administration, Case Institute of Technology; Mr. A. H. Gepfert, Operations Research Group, Case Institute of Technology; and Mr. Dale G. Graham, Assistant to the Executive Vice-President, Heyl & Patterson, Inc., Pittsburgh, Pa.

It is believed that both method and content of this approach are of particular interest to the practicing industrial engineer.

THE TEAM AND THE PROBLEM

Some Introductory Remarks

By K. T. Korn

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It is my task today to state a problem. Moreover, it is my job to state this problem in a rather unconventional context; that is, in relation to a *multidisciplinary team*. This presents some intrinsic difficulties.

First, because the problem of cost estimating is a part of a number of other problems, namely those of *organization*, in the broader sense, that of *communication* without which organization is inoperative, and finally that of *decision-making*, in the narrower sense.

Second, in considering the problem of engineering cost estimating one should consider the other as problems of higher mignitude which will not be possible in the available time.

Third, the case history which has been chosen as the basis for the statements my colleagues and I are about to make is a part of a *diagnostic* study; in this sense it should not be deduced that it is represented as *research*. The purpose of this study was defined as an attempt to discern problems, identify the reasons behind these problems, and finally to suggest *methods* by which such problems might be solved.

Four, because the problem under discussion was one of many discerned which was the cooperative effort of a ten-man team of which only five could be with us tonight.

Finally, because this study was conducted in a specific industrial setting, and hence, some generalizations can apply only to this, or very carefully compared situations.

The statement of a *Multidisciplinary Analysis of a Problem of Engineering Cost Estimating*, then, requires a statement relative to the multidisciplinary management research team, and second, a description of the industrial setting in which this team studied one set of circumstances.

In stating the problem, then, I shall attempt to make it clear that the problem of cost estimating which we are to discuss here, while it could definitely be identified as a problem, cannot be considered a self-contained one but rather a component problem within the superordinated ones.

Hence, it would add to clarity if it were possible within the framework of this symposium and its limitations to consider first the problem of *organization*, isolate from it the related one of *communication*, and finally discuss the problem of engineering cost estimating as one form of *decision-making* within the superordinated structures of organization and communication.

Neither the idea nor the practice of systematic inquiry are new. Nor is it a new experience that co-operative effort of a number of people working as a group is more effective than the efforts of one individual. The team, consisting of a number of members each trained in a different scientific discipline, obviously, is more effective than one which might be composed of the same number of individuals trained in the same body of knowledge. The advancements of this century supply us with many examples of the "products" of cooperative teams of scientists, technologists, and technicians with competence in many fields. The fact that this is so in the areas of technological, medical, etc., advancements —as is amply demonstrated by the development of the airplane, the jet engine, television, antibiotics, etc.—led to serious consideration and examination of the effectiveness of problem-solving activities in management.

The *policy-maker* in industry and business is faced with two general types of problems. The *technical* type of problem receives today a good deal of attention, thought, top management interest, and—last but not least—financial appropriation. This is rather well decumented by the statistics as they are published from time to time; for example, the $64 million annual research budget of one major manufacturer. This is not at all surprising for such research yields new products, new applications of existing products, cost-reducing modifications of products and processes—all of which is quite tangible, and can easily be interpolated into dollars and cents.

The second permissible classifications of problems is the *management* problem —the problem which arises as soon as the human element is introduced into the industrial and business process. This type of problem is more difficult to deal with. Its variables are more intricate to measure. Its general nature is more dynamic, more easily given to change. The skills required to deal with such problems are more varied, and usually not so abundant within an organization.

However, the interests of many have been drawn to this type of problem. The psychologist studies the behavior of individuals, and tries to answer such questions as, "Why do people behave the way they do?" The sociologist is interested in the behavior of groups, and studies such questions as "What motivates this group?"—"How are personal traits, attitudes and beliefs of employees associated with high productivity?" The industrial engineer concerns himself with the design of methods and procedures to improve the efficiency of human effort. Others are interested in different phases of this general area. It is not implied here that these efforts are not useful. Quite to the contrary! Doubtlessly, each has made its contributions.

What can be learned, however, from the unbiased examination of their successes and failures is that the bodies of knowledge which have been assembled by the different disciplines, all interested in some phase of management is far too complex to be mastered by any one man; but that groups working together as multidisciplinary teams can achieve results superior to those which each could accomplish by itself.

From this sort of thinking was born the idea of multidisciplinary management team research, *MR* for short, as we practice it, and on this basis was built an organization of scientists and technologists with competencies in the branches of science ranging the breadth of the spectrum from logic and pure mathematics to the humanities and behavior sciences. From this considerable pool were drawn the members of the *MR* team which concerned itself with the problems of the company whose case history we have chosen as a background

for this discussion. From this ten-man team five are with us representing the fields of management, methodology, communications, engineering, and psychology.

The foundation of the *MR* approach can be found in a few basic concepts:

1. The Effectiveness of the Team is larger than the summation of the Effectiveness of the individuals comprising the team.

2. A Problem cannot be solved unless it is known. This implies that a problem exists on three levels: (a) THE EFFECT LEVEL, or the level on which the symptoms of the problem become evident; (b) THE PROBLEM LEVEL, that is the definition of the area which has deteriorated, and finally, (c) THE CAUSE LEVEL, that is the demonstration of the reasons behind the problem.

This conception of problems makes it easier to see that, first, without systematic study one cannot be sure that a problem *is* known; second, that if problem-solving pressure is brought to bear upon its symptoms, the reasons behind it remaining unconsidered, the best that could be achieved is the temporary disappearance of the symptoms which, in turn, will make the reasons behind the problem infinitely more difficult to discern.

3. Diagnosis does not cure. While it is a valid statement to say that problems cannot be solved without diagnosis, diagnosis alone will not provide a remedy. In this sense, it is not the purpose of *MR* to *solve problems* but rather to make problems amendable to systemic attack, and to make *those having the problem more effective problem-solvers themselves.*

4. An Enterprise is an Organism-as-a-Whole. An industrial or commercial enterprise can be likened to a complex, living organism, not at all unlike a biological organism. As the biological organism must function as a whole, as an entity, so must the business organism. Its components must be coordinated to the purposes of the whole. Severed from the whole they become meaningless and often useless. An industrial organism, however, consists of a multitude of individual organisms, etc., and hence, in its entirety, it is infinitely more complex and more complicated. More complicated not merely to deal with but more complicated to understand. To attempt to solve the problem of—say—"an arm" of such a complicated organism by merely concerning oneself with that limb would preclude the possibility that its disorder might originate in some other part of the organism, for example, in the central nervous system.

5. Management knows its business. We, in *MR* believe that the people who "run" an enterprise know their business. It might be said that they are "experts in the things they do right." They need no one to tell them how to run their own business. What the 'manager,' the policy-maker, needs is assistance in diagnosing difficulties, having his problems stated so that they are susceptible to the scientific approach which has proved to be the most fruitful one yet developed in organized, productive, human endeavor, and the development of methods by which a company's own personnel can solve its problems. In that way the management of a company is helped to become more effective problem-solvers themselves. This is important when we remember that no panacea will ever evolve. There will always be problems, and the responsible people in industrial and business management will always have to deal with problems of management. Thus, a *MR* team sees its function truly as a *con*sultant, not as an *in*sultant.

So much for the philosophy and practice of the multidisciplinary team in management. To set the stage properly it is also necessary to tell you a little about the cooperating company. Above all, the company is a leader in its own field, the design, manufacture, and construction of special-purpose heavy materials handling equipment. It looks back to a history of almost seven decades of successful operation. They are not a large company. About four hundred employees produce, in round figures, ten million dollars' worth of annual sales. A sizable part of this is individually designed and constructed. A smaller part makes up a manufacturing program of designed apparatus where merely application modifications are required. In general terms they are in 'good' shape. Their financial position is sound. They discount their bills. Their banking relations are excellent. They make a profit. Their break-even point is high at about 40% of their volume, but it is under control. Their labor relations are satisfactory, and better than those of many other similar companies. Their labor turn-over is 'high' but less than that of others. Their management and technical personnel are competent. There are little fires every once in a while but they are put out quickly. They will flare up somewhere else, and be put out again. Their top management group is composed of capable, foreward-looking, even enlightened men.

They reasoned that it is well for a man to see his 'physician' every once in a long time to reassure himself that "all is well," or to detect the beginnings of illness early enough to deal with them more easily, not to wait for serious illness to strike! Their viewpoint regarding the future might be described as anticipatory of 'harder' times. The present top management guided the company through the depth of the depression. Successfully, as is evidenced by the fact that the company did not merely survive, but it grew. But the memory of the depression days is still vivid in the minds of the 'older' people. Many top positions have been filled since by 'younger' men who do not have the carry-over of the depression experience, and the top people are worried about their ability to meet conditions which might in some ways resemble those of the thirties. They believe that their company has gone through a period of ten to fifteen years of 'easy' business, and they believe that that will not remain that way. They wanted to find out how ready they were to meet such conditions if and when they would arise. An astute management, indeed!

A *MR* team of nine was composed. Its purpose was specifically not one of providing "cures," but rather a *diagnostic* one. What are the problems? What are the reasons behind the problems? What are the alternative solutions from which one could be selected?

The team was composed of one methodologist, one operations research analyst, one engineer, one industrial psychologist, one sociologist, one clinical psychologist, one market analyst, one biomathematician, and myself.

To these nine was added one employee of the company who was intimately familiar with its operations, personnel, and who enjoyed the confidence of top management.

Our team conceptualized the client company as a *process.* A process is a set of simultaneous and consecutive steps tending toward the attainment of a final state or goal. At each step there may be a set of alternatives among which one eventually becomes the next step of the process. Each step is the result of a decision, that is the selection of one from a set of alternatives. The efficiency of the process can be defined in terms of the contributions which the decisions make toward the likelihood that desired goals will be attained.

This process was studied (1) with respect to the individuals who perform it; (2) with respect to the equipment used in its performance; (3) with respect to the structural and functional organization of the individuals and groups; and finally (4) with respect to the process of decision-making.

By far the most momentous and weighty decision a company of this character must make is the preparation and submittal of bids and quotations. In the majority of cases a firm bid must be submitted before a contract can be obtained. If the bid is too high the contract may not be obtained. If it is obtained, a profit is likely to result. If the bid is too low, the chances that the contract will be obtained are higher—but so are the probabilities of its execution at a loss to the company.

In this sense then, the estimating procedure is a form of decision-making, and an extremely serious one at that. The process of decision-making, however, seems inseparable from that of communication, for the preparation and submittal of an estimate are a form of communication. The preliminary design of equipment which must precede the estimating and the estimating process itself, are important components of a company's communication process. Communication does not merely concern itself with "making statements," but concerns itself equally with the degree to which statements are

understood. Thus, it becomes inseparable from the people who do the communicating, and its effective design becomes a function of the degree of insight into motivational, behavioral, and interactional patterns which exist in a specific setting. This demands insight into the personalities of the individuals and groups comprising the organization.

A METHODOLOGIST'S APPROACH

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The term "methodologist" may be strange to some of you, and with good reason, for it is a relatively new branch of science. This history of science has consisted in part of a progressive extension of the types of processes which have been subjected to scientific study. First there were physical processes, then chemical, biological, psychological, and social processes subsequently became susceptible to scientific method. Most recently, the process of scientific research itself has been opened to scientific study. The result is "methodology," the scientific study of scientific method. This area is directed toward two objectives: first, an increase in the efficiency of research within familiar areas and, second, an opening of new areas to which familiar and newly developed scientific methods can be applied.

How does a methodologist contribute to increasing the efficiency of a process of estimating the cost of a proposed job? He begins with a recognition of the obvious fact that the process is one of estimation. Then he asks, "What are the fundamental aspects of the estimation process?" Every estimation procedure involves four questions:

1. What kind of data is pertinent to the problem?
2. How should the data be obtained?
3. How much data should be obtained?
4. How should the data be analyzed?

On what basis can these questions be answered? To say we want the "best" answer helps little unless we have an explicit criterion of "best." One such criterion which has had wide application is that of minimizing expected costs. That is, we can answer these four questions in such a way as to minimize the sum of the cost of obtaining the estimate and the cost of acting on the basis of the estimate once it is obtained. A correlated criterion which can also be used is that of maximizing the gain.

To see how the criterion of minimum cost can be used, let us first consider a very simple situation. Suppose we have a population of five elements whose values along some scale are 2, 3, 6, 9, and 10, respectively. The average value for the population, then, is 6. Now, suppose we do not know this value but want to estimate it on the basis of data obtained from a sample drawn from the population. It would be possible to select samples of 1, 2, 3, or 4 elements. How many should be selected? Let us see what is involved in getting a rational answer to this question. First, you will observe in column A of Table I all the possible samples, for each size, which can be selected from the population. For the moment, let us assume we are using a simple random sampling procedure; that is, one in which each possible sample has the same chance of being selected as any other sample of the same size. Further, suppose that we use the average of the sample as an estimate of the average of the population. In column B you will observe the resulting estimates. Now, the inaccuracy or error of each estimate can be determined simply by subtracting the true population average (6) from each estimated value. The results are shown in column C.

Sample Size	A Sample	B Estimate	C Error	D Cost of Error	E Expected cost of Error
1	2	2	—4	$24.00	$ 4.80
	3	3	—3	18.00	3.60
	6	6	0		
	9	9	3	9.00	1.80
	10	10	4	12.00	2.40
					12.60
					3.00
					15.60 = TEC
2	2, 3	2.5	—3.5	$21.00	$ 2.10
	2, 6	4.0	—2.0	12.00	1.20
	2, 9	5.5	—0.5	3.00	0.30
	2, 10	6.0	0		
	3, 6	4.5	—1.5	9.00	0.90
	3, 9	6.0	0		
	3, 10	6.5	0.5	1.50	0.15
	6, 9	7.5	1.5	4.50	0.45
	6, 10	8.0	2.0	6.00	0.60
	9, 10	9.5	3.5	10.50	1.05
					6.75
					6.00
					12.75 = TEC
3	2, 3, 6	3.67	—2.33	$14.00	$ 1.40
	2, 3, 9	4.67	—1.33	8.00	0.80
	2, 3, 10	5.00	—1.00	6.00	0.60
	2, 6, 9	5.67	—0.33	2.00	0.20
	2, 6, 10	6.00	0		
	2, 9, 10	7.00	1.00	3.00	0.30
	3, 6, 9	6.00	0		
	3, 6, 10	6.33	0.33	1.00	0.10
	3, 9, 10	7.33	1.33	4.00	0.40
	6, 9, 10	8.33	2.33	7.00	0.70
					4.50
					9.00
					13.50 = TEC
4	2, 3, 6, 9	5.00	—1.00	$ 6.00	$ 1.20
	2, 3, 6, 10	5.25	—0.75	4.50	0.90
	2, 3, 9, 10	6.00	0		
	2, 6, 9, 10	6.75	0.75	2.25	0.45
	3, 6, 9, 10	7.00	1.00	3.00	0.60
					3.15
					12.00
					15.15 = TEC

TABLE I

Now, let us suppose that each error of overestimation costs $3.00 per unit of error, and each error of underestimation costs $6.00 per unit of error. Then, in column D, we can enter the cost associated with each error. But we do not know beforehand which error will be made. Nevertheless, we do know what the chances are that we will make that error. For example, there are five possible samples of one element, and—according to the method we are using—each sample has an equal chance (1/5) of being selected. Therefore, each error has the same chance (1/5) of being incurred. Then, the first error listed for samples of 1, is—4, and its cost, $24.00 will be incurred in the long run 1/5 of the time. On the average, then, this error will cost 1/5 ($24.00), or $4.80 per estimate. This is the expected cost of this particular error. The expected cost of each possible error can be computed similarly. They are shown in column E. The total for each group in column E is the total expected cost of error; that is, the average cost of error that will be incurred if the procedure is used repeatedly.

Now, suppose each observation costs $3.00. Then, the cost of observation for the various sample sizes is $3.00, $6.00, $9.00, and $12.00 respectively. If we add this sum to the total expected cost of error we obtain the total expected cost of the procedure, TEC. You will observe that, for this illustration, samples of two elements are the most economical in the long run.

Similar computations could be made for other sampling and estimating procedures which can be applied to this problem. That method should be selected which would yield the lowest total expected cost.

The procedure just illustrated can be expressed in general terms, as follows: Let e_i represent an error of estimation. Further, let $C(e_i)$ represent the cost of that error, and $P(e_i)$ represent the probability of making that error. Then, the expected cost of that error is $C(e_i)P(e_i)$, the product of the cost and the probability. The total expected cost of error can then be expressed, as follows:

$$C(e_1)P(e_1) + C(e_2)P(e_2) + \cdots + C(e_n)P(e_n) = \sum_{i=1}^{n} C(e_i)P(e_i)$$

Now, if K is the cost of taking one observation, and n is the number of observations taken, then nK is the cost of obtaining the sample. The total expected cost of the procedure (TEC), then is given by the following equation:

$$TEC = nK + \sum_{i=1}^{n} C(e_i)P(e_i)$$

One difficulty seems to appear: In a real situation—though we might be able to determine the cost of a specific error—how can we determine the probability of making that error? But this is not a real difficulty because sampling and statistical theory provides estimates of this probability for any sample size. That is, the probability $P(e_i)$, can be expressed as a function of the sample size, n, and the error e_i:

$$P(e_i) = f(n,e_i).$$

To determine which value of n minimizes the total expected cost of the procedure the methods of differential calculus can be used. We take the derivative of TEC with respect to n, set the result equal to O at the minimum point, and solve for n.

Now, you might say, suppose this approach is applicable to estimating characteristics of a population, how can it be used in estimating the cost of a job? Well, let us see.

First let us set aside practicality and set up an ideal procedure, one we would like to follow if we could. Then, we can consider how close to the ideal it is possible to come.

The variables involved in job-cost estimating can be represented, as follows:

t=hours spent in preparing the estimate;
c=cost per hour expended in preparing the estimate;
p=probability of getting the contract for the job estimated;
k=estimated cost of the job to the estimator;
k′=actual cost of the job (if obtained) to the estimator;
k″=contract price of the job;
G=expected gross profit from the job.

The expected gross profit can be expressed in the following equation:

$$G=p(k''—k')—(tc).$$

The values of p and (k″—k′) can ideally be expressed as functions of t, the time spent in preparing the estimate; that is

$$p=f(t)$$
$$(k''—k')=g(t)$$

To maximize the expected gross profit, an optimum value of t is sought, just as in the earlier illustration an optimum sample size was sought. This optimum time can be defined mathematically, as follows:

(1) Take the derivative of G with respect to t:

$$\frac{dG}{dt}=\frac{d[p(k''—k')—(tc)]}{dt}$$
$$=\frac{d[f(t)g(t)]—(tc)}{dt}$$

(2) Determine if $\frac{dG}{dt}$ is a maximum.

(3) If it is, set $\frac{dG}{dt}$ equal to zero, and

solve for t. The value of t thus obtained would maximize the expected gross profit.

So much for idealizing the procedure. To use the procedure, estimates of the function f and g are necessary. These values might be obtained by preparing and analyzing data compiled in the following way (see Table II):

By using such a table on the estimating procedure employed by a company, estimates of the functions might be obtained. But even if such estimates cannot be obtained, the model can serve as a heuristic device for making explicit what data should be obtained in the future so that the estimation process can eventually be brought under control; that is, it opens up the possibility of eventual (if not current) improvement in cost estimation.

TABLE II

(1)	(2)	(3)	(4)	(5)	(6)
t	k	k″	Contract obtained (yes-no)	if - yes k′	k″-k′

This particular model for job cost estimating is not applicable to all cases; variations would be required by special cases. It is applicable to the company we are considering.

The construction of an ideal procedure does not provide a final answer; rather it provides a beginning for obtaining a provisional answer. For example, in job-cost estimating, the job-cost itself is usually a secondary estimate. By this I mean that some other property of the job is usually first estimated, such as manhours required, or material required. Then a conversion factor is used to translate this estimate to one of cost. Hence, it is critical to know how good is the primary estimate, and in particular, how reliable is the conversion factor. This phase of estimation was the primary concern of the engineering member of our team.

Further, assuming that a good method has been developed, there is no guarantee that it will be used efficiently unless certain organizational requirements are met. These requirements are psychological and social in character. Cooperation and communication among participants in the organization's activity are necessary for the successful application of any problem-solving procedure. These aspects of the problem were studied by the psychologist and the communications expert of our team.

THE ROLE OF COMMUNICATIONS

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The analogy drawn between a business enterprise and an organism is more than a figure of speech. In maintaining its functions and integrity, a business enterprise solves problems which are essentially of the same kind as those which organisms face. Just as an organism, constantly faced with the ever-changing environmental situation, must constantly adjust its behavior so as to meet the situation adequately (that is, preserving its integrity and its functioning capacity), so must a business enterprise.

We use the term "organization" to designate the faculty which living organisms have in dealing adequately with situations. The essential part of the organization is the communication apparatus. When the presence of obnoxious substances or of food is reported by the sense of smell, and the muscles take appropriate and coordinated action, we know that the organism's communication apparatus has functioned properly.

Similarly in business, when certain conditions of the market are evaluated by certain responsible personnel, and appropriate action is taken by other responsible personnel, we know that effective communication has occurred.

Before we examine the role of the communication process in an enterprise as it affects cost-estimating procedure, I would like to say a few words about the communication process in general. Whenever it occurs, communication can be of many different kinds, and depending on what role of communication we are talking about, we can classify its occurrence accordingly.

For example, we can classify different kinds of communication flow according to the functions they perform in the organization. Suppose we have an organizational chart such as is represented in TABLE III.

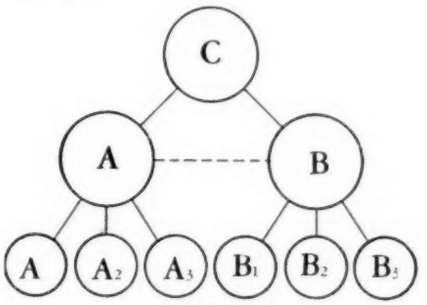

TABLE III

Here authority is concentrated toward the top. Ordinarily, communications flowing up the channels carry information which results in decisions affecting the sources of the information.

Communications flowing down the channels ordinarily carry directives. Communications flowing along the same level of authority (as from A to B) serve to coordinate decisions affecting separate groups. In some types of organization, for example, in the rigid military structure where everything goes "through channels," information can travel only up and down the channels but not across.

Besides this spatial or "topological" classification of information flow we may classify communication according to the role it plays in the time dimension. One can communicate with the past, with the present, and with the future. One communicates with the past by consulting available records of what has occurred. Memory, of course, is a special kind of record. One communicates with the present by utilizing the available spatial channels of communication within the organization and those to and from the outside. For example, one obtains information from publications, and one disseminates information through advertising. One communicates with the future by making records to be available at a later time.

There are many other aspects to communication. In fact, the subject forms today an entire field of inquiry with its own areas of research and specialization. But for the purposes of our discussion, an examination of these two aspects—the spatial and the temporal—will suffice.

The cost estimating procedure obviously involves an evaluation and a decision. As such, the procedure is an act of ad justment to a certain stimulus; that is, a prospective job which an enterprise would like to undertake. The sort of de-

cision made will determine whether the job will be undertaken at all, whether—if undertaken—it will be profitable, and whether its completion will enchance or inhibit the opportunities for undertaking other jobs in the future.

From the point of view of a business enterprise in a competitive situation the criteria for a sound cost estimating procedure are perfectly clear: The cost must be estimated neither too high nor too low. For, if it is estimated too high in a competitive market, the chances of undertaking the job at all will be diminished, and if it is estimated too low, the job will not be a profitable one, or, if adjustments in the contract are allowed, the good-will of the customer may be lost.

Now then, how is one to know whether one makes 'good' estimates. An obvious way to find out seems to be through the examination of past performances. But what can be learned from such examination? As an example, allow me to take the case of one industrial enterprise where our team recently conducted a diagnostic analysis of the engineering cost estimating procedure.

An examination of the company's records showed that "over-runs" rather than "under-runs" were the rule on the jobs undertaken. Several of the company's executives were interviewed on this matter, and all agreed that jobs tended to over-run, a fact which they interpreted to mean that under-estimates rather than over-estimates of cost were the rule in their company. But does it necessarily mean that? To see whether over-estimates or under-estimates prevail, one must examine *all* the jobs for which the company has prepared and submitted bids, not just those which were actually undertaken, since it stands to reason that many of the over-estimated jobs were lost to competitors, and therefore, that the balance was stacked in favor of the under-estimated jobs.

None of the executives interviewed brought out this point. Instead, they blamed the predominance of under-estimating on a lack of proper information, on unreliable formulae for estimating labor costs, on the decline of productivity of the American worker, which, in turn, they explained as stemming from his rising sense of security, labor union activity, etc., etc.

Now, it may well be that all of these factors are operative. However, it is obvious that the situation can be hardly effectively improved if one does not know which factors are the most important, or at least, which factors can be most directly affected. It is possible that the American workers' "sense of security" is somewhat responsible for a declining rate of profit—although I wouldn't bet on that—but if some other factors can be tackled more easily, it stands to reason that it pays to concentrate on them rather than give way to nostalgia for the 'good old days' of speed-up incentives.

I repeat, in order to change any situation one must uncover the factors which one can *effectively manipulate*. This is true to the extent of being trite; but many such obvious truths, although recognized on a verbal level, are seldom *acted* upon.

Let us now come back to the cost estimating procedure. One must, of course, determine first of all whether one actually produces good estimates. And, as I said before, a mere count of over-runs and under-runs is not enough. It must be expected that there will be some bias in favor of over-runs in any company's record because under-estimated jobs which tend to over-run are selected for in a competitive situation. The question is not whether there is a bias. The question is how much bias should there normally be? This question can be answered only by appropriate research. The techniques of such research are beyond the scope of this paper. They obviously fall within the realm of communication, in this case the availability to the company of information concerning the status of over-runs and under-runs in other companies, and certain statistical considerations such as the relation between the size of the over-estimate and the probability of losing the prospective contract, and similar matters.

Let us now suppose that this information has been obtained, and that a discrepancy is found between the actual and the optimum estimating habits. The question now arises on how to improve those habits. This brings us to the functioning of the communication apparatus within the company. It is another truism to say that the better this apparatus functions the more accurate will be an evaluation of the important factors which determine the estimate. It is, however, necessary to be more specific with regard to what constitutes a good communicative apparatus. One could ask the following questions:

1. *Are the prescribed channels of communication adequate to carry all the information necessary for the cost estimating procedure?*

In any business organization there are prescribed channels of communication. They may not be as rigid as in the military, but they nevertheless exist. For instance, the dissemination of work sheets, blue prints, etc., is obviously determined by the quantity of the duplicated material, and this constitutes a constraint on the available channels of communication.

2. *Is too much information sent through the prescribed channels?*

One of the important complaints made by the technical personnel of the company which is serving as a case history was that they had to spend too much time abstracting the information they actually needed from that which was sent to them.

3. *Are the prescribed channels actually used?*

In other words, are the directives and instructions actually read, or are they merely disseminated? A pertinent question is also whether they are written in a language which is conducive to being read.

Or, on the personal communication level, if it is expected that personnel will seek advice from their more experienced superiors, do they actually seek that advice? Is the personality of the superior such that his subordinates want to seek his advice?

4. *Are the informal channels of communication utilized?*

Anyone who has been in the Army knows that if communication had been strictly confined to "official channels," we might have lost the war. Every supply officer knew that the way to get supplies on time was to be buddies with all the other supply officers in the theater so that one had informal "under the counter" information about what was available where.

In a business organization such informal channels have an opportunity to operate where people are friends as well as co-employees. In this way information, experience, and know-how are exchanged that never have a chance of getting into the directives, circulars, etc., because the people who write the directives do not speak that sort of language.

5. *Is there "feed-back"?*

When directives are sent down the line certain actions result. Do those who send the directives know the effects of those actions, and, if so, do they evaluate those effects so as to send 'better' directives the next time? This does not ordinarily happen if decisions are made exclusively in the air-conditioned solemnity of the directors' meeting, and the direct action is confined to the racket of the shops and the tribulations of the salesman.

So much for the general operation of the spatial communication apparatus within the company which influences the decisions which, in turn, determine the cost estimating procedure. When we turn to the temporal aspects of communication, the evaluation of records, the bearing of this process on cost estimating procedure becomes ever more apparent.

Here, the operation of feed-back is of prime importance. Since cost estimating procedure is constantly repetitive, it follows that it can be constantly improved if a learning process occurs; that is, if the results of each operation are fed-back into the information of which future operations will be based.

One must, of course, have accurate records. Here, the structural make-up of the organization is again important. One cannot have accurate records if—as is the case in some companies—the various departments compete with each other trying to maneuver the estimates in such a way as to minimize the costs charged to them in order to show a departmental gain regardless of the fact that there is a company loss. One cannot have accu-

rate records if the "incentives" used in the company consist of threatening people with disfavor if they make mistakes; this usually results in doctored-up records.

But even with the most faultless records no progress can be expected in the cost estimating procedure if the procedure itself is not modified as a result of experience. Here again, the analogy between the enterprise and an organism becomes meaningful. The ability of the organism to adjust to challenging situations only seldom consists of a complete repertoire of reactions to standard sets of conditions. In all higher animals this involves the capacity to learn; that is, to change the behavior patterns with each new situation so that the next time the situation occurs it will be met more effectively.

Thus, an enterprise which continues to use the same estimating procedures year after year because that is what each department head is used to and that is what he teaches his successor, is not functioning as an organism in a rapidly changing environment should function. A most important aspect to the temporal communicative process is, therefore — aside from the availability of accurate records and the ability to evaluate them —a learning potential, a feed-back device in which the accumulated experience actually counts.

This happy state of affairs can come about only if the responsible personnel are aware of how the communicative process operates. And this awareness can come only with a broad background and interest in things other than those immediately concerned with one's job.

AN ENGINEER'S APPROACH

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To an engineer the solution of any problem resolves itself into determining the objective or objectives of the solution, the degree of accuracy desired and the kind of data that are necessary to achieve the stated objectives.

The objective of an estimate is to provide a concern with the cost of doing a unit of work. The term unit of work is used loosely as it might mean the cost of producing a can label or the cost of producing an entire manufacturing plant. The estimate itself might be used in various ways. It may be used to establish a firm bid quote on a unit of work or in a control function like scheduling, purchasing, and preparing a budget.

The degree of accuracy required may well vary with the use that is to be made of the estimate. It is a well known fact that the cost of producing an assembly rises with the degree of precision required in the manufacture of its components and it is logical that the same would hold true for the expense involved in preparing all but the simplest of cost estimates.

We assume that a company is in business to make a profit, and to provide the investors with a reasonable return on their investments in the form of dividends. We shall assume that the management's process of decision-making is designed to achieve this goal continuously. Furthermore, no designed process or procedure is ideal, or perfect, or that it functions so well that it needs no improvement. As Dr. Rapoport has pointed out, it is necessary for a business to have the quality of being able to adjust to changes which occur continually, and quite similarly to the same ability of the biological organism to adjust to ever-changing conditions. While this is generally true, it applies even more so to the design and execution of procedures of the importance of cost estimating.

The characteristic of continuous improvement is achieved by considering a procedure "imperfect," and by providing a feed-back mechanism by which the procedure itself can be objectively evaluated and improved. This application of the feed-back principle will not merely detect and correct defects which were incorporated in the original design of the procedure, but also defects arising out of changing conditions not anticipated at the time of design.

The examination of what data are necessary for producing a cost estimate may begin at the point of cost accounting; that is, with the record of the work after it has been done. The cost accountant assembles the cost of a job by dividing the expenditures into three categories:

1. Direct Labor Cost; that is the cost of all labor which can be directly allocated to a specific job (exclusive of overtime premium, etc.).
2. Materials Cost; that is, the cost of all materials which go directly into the making of the product.
3. Overhead, or Burden, that is, the accumulation of all other expenditures of general nature which cannot be (a) directly associated with one job, and (b) such expenditures which can be directly allocated to one job but which would distort the record of the job cost, such as overtime premium, or sub-standard performance "make-up." The total overhead is prorationed by some fixed formula over all the jobs dones within an accounting period.

The accumulation of such costs is usually done in a systematic fashion. Labor tickets are provided for direct and indirect work, and time and type of work are recorded. Materials are similarly controlled through inventory and purchasing procedures. The determination of overhead and its distribution is of lesser concern to the engineer, particularly in view of the fact that he can seldom exercise any sort of control over such expenditures.

The accuracy of the accounting of costs becomes a function of the completeness and veracity of the original recordings of labor and materials, and their correct allocation to the proper job. Thus, it may be said that cost accounting ideally is a replica of what has actually happened.

This is not so in cost estimating. Estimating, in effect, is a prediction of what a job, a service, or a product is going to cost. The accuracy of such a prediction depends upon the estimator's knowledge of (1) the final design of the product to be manufactured; (2) the materials required; (3) the operations necessary to be performed; (4) the tools and equipment by which these operations will be performed, and (5) the time required to perform each operation.

The development of reliable records to provide the estimator with such information depends to a large degree upon the type of industry which produces the product. An industry which manufactures large quantities of the same product can, in time, establish quite accurate records. Such records usually take the form of operation instruction sheets, routing sheets, and standard time tables. The routing of a part, sub-assembly, etc., can be, and often is, a part of the engineering function; that is to say, that the engineer does not merely specify what is to be made, but also how it is to be made, the tools to be used, the methods to be employed, etc. Time values can be established by numerous methods.

The availability of such records, and their reliability, however, decreases considerably as the size of the average production run decreases. To achieve a relatively high degree of reliability in an industry having an average production run of, say, 10,000 pieces is not too difficult. The industry which never produces more than 500 pieces of one design has a more serious problem of developing accurate data, and its problem of producing an estimate is considerably more difficult. As the size of the average production run approaches 1, the difficulties of producing a reliable estimate grow unproportionately.

Such difficulties are even further amplified in companies engaged in so-called contract manufacturing, such as the art metal industry, fabricators of sheet metal systems as heating, ventilating, and air-conditioning, and special purpose equipment builders, as for example the oil-well equipment and supply industry, and special materials handling producers. Within this class of fabricators a further difficulty may be observed in the cases of those manufacturers whose policy it is to render a complete service, that is to say that the concern that merely fabricates, assembles, and erects according to engineering design and detail furnished by the buyer is confronted with an estimate problem of somewhat lesser magnitude than the company which also engages in the design of the equipment, its fabrication, subassembly, job site assembly, and its estimator with a finalized and detailed erection. The former can at least supply design. The latter is forced to produce

an estimate on the basis of a preliminary design; often produced with little or no knowledge of the job site conditions. While it is by no means intended to convey the impression that the intrinsic difficulties of estimating on all levels of manufacturing are widely different, it is pointed out that the type of production process varies from mass production to single unit production types, and that the difficulties of producing a reliable estimate increase with the decrease in the production run size.

The most difficult conditions are encountered by the company that renders the most complete service, that is to say, the one which includes in its estimate the cost of engineering, fabrication, job site assembly, and erection of an installation, and which uses such an estimate to make a firm bid or a binding quotation to the prospective buyer. It is such an organization that we are considering here. This places a high premium on the accuracy and completeness of the preliminary design, or proposal drawings, and it entails a certain risk of spending time on this phase of work, particularly in view of the experience of such industries that the yield of contracts received varies from 5% to 25% of contracts which were bid. This would indicate that even under the most favorable conditions, there is one chance out of four that the bidder will receive the contract, and normally the risk would be much higher. The problem of optimizing cost estimating time has already been discussed by Dr. Ackoff. I shall concern myself with a discussion of the types of information which are necessary to evolve an accurate engineering cost estimate as they are related to the particular type of industry described before.

The cost of materials is, obviously, a major item in any estimate. Materials, in this case, are divided between structural items and machinery and equipment items. The structural items consist primarily of rolled steel shapes, rivets, plates, etc., for the superstructure, and do not, in general include structural items such as reinforcing steel for concrete foundation work. The foundation work is generally supplied by the buyer.

The cost of structural materials such as rolled steel shapes is primarily a function of their weight. The selection of structural materials which are in the main load-carrying elements depends upon the spans, the loads, and on the type of construction, that is, riveted, welded, simple, or statically indeterminate. These decisions must be made before even an approximate analysis of the size of the structural members can be made. Since most structures are indeterminate to some degree, it is necessary that simple, approximate formulae be evolved, in certain cases, for the determination of the sizes of structural members. These formulae can be improved by subsequent correction possible through the more exact analysis of the actual jobs which are engineered.

The selection of equipment items depends on capacities, cycle times, and operating conditions. Their selection is simpler, generally speaking, than that of the structural items.

Perhaps the most difficult phase of the estimating job is the estimating of shop fabrication time. It was previously pointed out, the average production run of the company under consideration is 1, type, sequence of operations and methods of handling, etc., are decisions made in the shop, routing is non-existent, and hence, no operational break-down exists on the basis of which operational times could be accumulated. "Indirect" labor is often included in "direct" labor times, rendering historical information extremely unreliable. The establishment of a routing routine and the determination of standard times by some established system would be uneconomical because of the fact that only one piece of equipment is being produced. This introduces so many variables and unknowns into this problem that it presents a real challenge.

It is obvious that there is no one simple answer to this problem, such as "shop hours per ton of steel fabricated"; even though this practice is widely used in this and many similar industries. This comes even more apparent if we take, for example, just a simple ¼ inch flat plate tension member which is joined to its supporting member by a single V-groove butt weld. If we double the load in our original design, then, the size of the member and consequently its weight would double. Let us assume that we double the size of the member by making it the same width but ½" instead of ¼" thick. The cost of preparing the ends of the two members for welding might be roughly the same because the preparation time is a function of the width of the pieces rather than the thickness of the material. If we examine the time necessary to perform the actual welding by taking the time values from Lincoln Electric's *Procedure Handbook of Arc Welding*, we find that the ¼" plate can be butt welded at a rate of 27 ft./hr., and the ½" plate can be welded at the rate of 19 ft./hr. There is no allowance in these allotted times for positioning and turning the work, chipping, etc., as these would obviously depend upon the actual conditions and facilities existing in the particular shop and on the particular job. Comparing the actual time of welding, however, we find that a member twice as heavy may be connected in 1.42 times as long. The amount of electrode used, however, for the ½" plate is about three times that for the ¼" plate.

The cost per pound of producing an installation can often, by coincidence, be a good criterion of the cost of producing similar installations. I was amazed at some figures compiled by a Cleveland manufacturer of household appliances who took eight different competitive makes of a particular appliance, completely dismantled them and prepared detailed estimates of the cost of producing each manufacturer's appliance. The designs were widely different particularly in the number of fastening operations necessary in assembly. The lowest having about 100 such operations and the highest over 200. When the costs were completely analyzed it was found that the variation in cost per pound between the high and the low was about 2 cents. One can find the same coincidence by comparing the cost of similar models of the big three automobiles. No doubt the cost per pound would be approximately the same, however, it would certainly be an error to assume that this is the cost per pound of all automobiles.

The case in point is simply that a system of record-keeping must be adopted by which unit times for some adequate operational units will evolve. It is very doubtful that a simple parameter like weight of steel fabricated will suffice, except in the case of geometrically similar structures fabricated in a similar manner. It could be expected that weight, length of member, type of operation, and the geometric shape of the subassembly are pertinent variables to be considered in estimating shop times. These variables can be correlated by setting up a system of record-keeping on each job so that eventually reliable information becomes available to the estimator.

It is difficult to predict the time necessary to engineer a job because it is almost impossible to evaluate the efficiency with which a professional man does his work. Engineering, is, in part, a creative activity, and as such does not lend itself too readily to an accurate performance evaluation. One factor which must not be overlooked is that additional time spent in engineering may well show up as a savings in materials, shop labor, and erection time. Here again, the importance of record-keeping in the engineering department and in the shop cannot be over-emphasized as a way to evaluate the existence or lack of such savings.

Finally, the estimator is faced with another difficulty. In the case at hand, erection jobs are done by crews obtained from local "hiring halls" under the supervision of the seller's erection superintendent. This is unfortunate from the estimator's point of view because of the fluctuations in the quality of the crews, not merely from job to job, but even from period to period on the same job. In some instances it may mean that all of the skills required for the efficient completion of the erection job are not even available to the superintendent. Accurate daily reports on man hours and equipment hours prepared and maintained with uniformity, and analyzed in terms of significant parameters like weight, length, goemetry, and job site conditions might yield information on the basis of which the estimator could make predictions with a higher degree of reliability. The need for accuracy of these

figures cannot be overstressed. If for example, an erection superintendent records the time for setting a pier leg against the span erection time in a way that his figures will jive with his erection schedule, then of course, nothing is learned.

A post-mortem on each job—whether it went well or badly—would be a further part of a feed-back mechanism by which the process of self-improvement and self-education could continue.

The economical development of a reliable engineering cost estimating procedure depends upon accurate record-keeping by the proposal engineering department, the engineering department, the purchasing department, the shop, and the erection superintendents. A cooperative effort of all of these in correlating these records with the significant cost parameters will evolve information to the hands of the estimator which will continuously increase the degree of reliability of his estimates. This will provide the company with a higher yield of contracts obtained, with an assured margin of profit to be attained, and last but not least with a knowledge that any recurring inefficiencies throughout its enterprise can be dealt with in a systematic fashion.

HUMAN FACTORS

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It may seem strange to you to include a paper dealing with problems of human relations in a symposium concerned with engineering cost estimating practices. I think that you are probably all aware of, and perhaps accept, the idea that there are human relations problems involved in selling and in managing. Nobody is so naive, nowadays, to think that a good product sells itself, although even if it did, there would still be human relations problems involved, in that a need or desire for a product must exist in, or be felt by, the potential customer before the product will be bought.

Most people, I think, now realize that a company does not run itself on the basis of a good organization chart alone, but that the needs, wishes, and motivations of the individual members of the company and the interaction and interrelationships between the individuals and groups must be recognized and dealt with to insure smooth operation. Even the design of an organization chart, and surely—what is perhaps more obvious—its proper functioning, is more a problem in human relations than one of technical planning alone. Many managers, I am sure, have stubbed their toes on the consequences of the oversimplification that occurs in organizational charts which forget the individuals and see only their defined functions.

I believe that most people—at least those people who are charged with the responsibility for management—realize that a company is more than an aggregate of capital stock or equipment — physical plant or merchandise — more than an aggregate of methods, techniques, or operations—more even than an aggregate of individual brains, talents, and personalities—and more than a mere additive combination of any or all of these factors.

But I wonder how many people, even those engaged in management, view a company—any company—as a social organism, subject to the same social laws as any other social organism and understood only by the same methods of conceptualization which apply to any other social organism. Any social organism, at the human level, has its roots in the relations between and among the individual human beings comprising it, and problems associated with human relations permeate every level of operation of that social organism, even engineering cost estimating practices.

That accurate estimating is an operation that is vital to the success of a business enterprise needs hardly be argued or defended. Estimates which are too high discourage potential customers — and a business cannot exist without customers; estimates which are too low eat into profits, or result in losses—and a business cannot long survive on losses, or merely breaking even. The purpose of estimating, then, is to arrive at a reasonable price for the merchandise; reasonable from the points of view of both the buyer and the seller; it must be within the means of the buyer to buy, and it must at the same time allow a fair margin of profit to the seller.

What is involved in the process of estimating? The discussions of my colleagues on this panel seem to permit a general statement that estimating is a matter of accumulating and organizing the objective and observable facts, converting these facts into dollars-and-cents measures, and totalling these measures to arrive at a reasonable price for the merchandise. You may ask, What is psychological about that? You may be willing to grant that there are psychological factors involved in the matter of a "reasonable price"—many papers have been written, and read by all of you, which concern themselves with "the profit motive" and "buyer needs and resistance." But where do problems of human relations enter into the estimating procedures themselves, which are technical and factual in nature, however complex the technical problems may be?

In my overly simplified definition of the estimating process I emphasized the words "facts" and "factual." We tend to make a sharp distinction between matters of fact and matters of opinion or inference or speculation. Somehow facts, even though they may be unpleasant or distasteful, have considerably more respectability than ideas or theories. We tend to look upon "facts" as entities having an independent existence in the external world of reality as contrasted with ideas or theories which dwell and have their being only in the minds of men. Facts give us a feeling of comfort and security, for they are tangible things we can grasp, hold on to, and lean on for support.

It is perhaps too philosophical to argue here the matter of whether or not a "fact" has any existence at all unless it is observed. You would perhaps be more willing to accept without extensive argument or defense the idea that a fact has very little, if any, significance unless it is observed, interpreted, and reacted to. That a tree falling in a forest makes a noise is a "fact" that we all accept, although philosophers have been arguing for years as to whether or not there is any noise if there is no ear to hear it. But whether or not the falling tree makes a noise makes very little difference to anyone (except maybe the philosophers) unless the noise affects someone in some way—in other words, unless it is heard, interpreted, and reacted to.

Now, for a fact to be observed, there must be an observer. For it to be interpreted, there must be a perception and a mind to perceive. For it to be reacted to, there must be communication. So, in this sense, a fact has no meaningful existence outside the mind of the observer; consequently, what we glibly call a "fact" is not the phenomenon itself but the subjective experience of the objective reality.

Armed with this conception of "fact" it would be possible to examine and analyze each step in the estimating process in terms of the observation, interpretations and communications involved in order to determine the degree to which psychological or human relations factors enter into each. Wherever estimating practices seem to yield unsatisfactory results, such a systematic analysis would undoubtedly be fruitful and probably necessary in order to arrive at optimum procedures. However, this would be a task far beyond the scope of this paper which can only point to areas where human relations factors play an important role. I can only hope that given this orientation you can make your own analyses on whatever level may be most useful to you.

Since much of the estimating process is based on record of one kind or another, let us consider some of the human problems involved in the construction and utilization of such records. Records are frequently looked upon as facts which can be used as a basis for estimating with a high degree of confidence. But, just what is a record? It should be remembered that a record is merely a representation, more or less complete, of an observed phenomenon. Complete records (examples of which might be motion pictures and sound recordings) must be condensed in order to be effectively utilized. For a phenomenon to be observed there must be an observer. What are some of the factors which may influence an observer in making a record?

First of all, we might consider the effect on the record-keeper of his under-

standing of what use is going to be made of the record. I think that you would all agree that an observer who thinks his record is going to be used to keep tabs on the efficiency with which he handles his job to the end that decisions can be made as to whether he will be retained or fired, demoted or promoted, will be differently motivated from the recorder who knows that his record will be used merely in a compilation of anonymous statistics. The individual in the first instance is highly motivated to make the record the best possible showing, regardless of the particular kind of record he will be called upon to keep, whereas the individual in the second instance has less at stake, or conceivably, it may be to his advantage to make a poor showing.

For an example of how the accuracy of records may be affected by lack of understanding of the use to which a record is to be put, we might look at the company already cited as illustrative of other points. In this company, the supervisor in the field keeps records of man hours spent on the various phases of the erection job. He, of course, is in possession of the estimates as to the "allowed" time which it was estimated would be spent on these various phases. He, quite naturally, in the face of any evidence to the contrary, looks upon these estimates as quotas to be met. The consequence of this view of his records as a measure of how well he has managed to direct operations so as to conform to the quotas set is fairly inevitably a juggling of figures so that the record of the actual time spent will agree as closely as possible with the estimates. If for some reason or other time is saved on one phase, or operation, the overrun on some other operation will be balanced by charging some amount of the overun operation to the one which was underrun. In this fashion, errors of estimation based on such records keep on compounding themselves, encourage further juggling on future jobs, and do not provide for the refinement of the data from which the estimator produces the estimate. If the supervisor in the field were explicitly informed, and if he thoroughly understood that discrepancies between his records and the estimates would not be viewed as evidence of inefficiency, or even of efficiency, but that the sole purpose of the records was that they should serve as a basis for more realistic estimating, then he might be motivated to keep records which more accurately reflect what actually occurred on the job. It would be to his advantage to keep accurate rather than fictionized records, since time quotas could be set which it would be more nearly possible to meet.

Whether or not an observer will deliberately falsify a record depends on additional psychological factors which must be understood in order to minimize the possibility or probability of falsifications occurring, and in order to evaluate the usefulness of any given record. The degree to which a person will resist the temptation to falsify or distort a record depends not only on the character of the individual—that is, his fundamental honesty—but also on his estimation of the importance of the record to him, personally, and to others or the company as a whole. If he thinks, for example, that his record will simply go to swell the already voluminous accumulation of papers that nobody ever looks at, he is not likely to view accuracy as very important. Demonstrating to him how his record is a vital link in the chain of company operations, and that as such it is important to the welfare of the company, and thus ultimately to his own welfare, is a problem in human relations. If the importance of the record cannot be demonstrated it is probable that it should not be kept at all.

I should like to insert a footnote here with regard to the conception of fundamental honesty as a character trait by pointing out that all we mean by this is the degree to which an individual can withstand the pressure exerted by his estimation of the advantage to himself of being honest or dishonest, and his estimation of how much distortion constitutes dishonesty. This is never a constant factor but one that varies with the situation and the individuals' own needs at a particular time.

Deliberate or semi-deliberate falsification is not the only source of error in recording. Observations to be recorded involve the perceptions of the individual making the observations. There is already an impressive body of evidence, accumulated from systematic and rigorous investigations, that the way in which an individual perceives an event is a function of his own highly subjective needs and tension systems. Perception itself can be, and often is, interfered with, narrowed, distorted or even entirely blocked off by highly individualized factors which are psychological in nature. Interpretation of the events perceived can, and often does, result in further distortion, depending on the subjective meaning which the perceived event has to the individual perceiving it.

So far we have discussed some of the problems involved in the accumulation of some of the data upon which estimates are based; that is, problems having to do with observation, interpretation, and recording. This is by no means the whole story, even so far as the gathering of information to be fed to the estimators is concerned. But let us go on to the next step in the estimating procedure: namely, problems associated with the utilization of the information accumulated. These are largely problems of communication and cooperation in which psychological factors are of paramount importance.

Cooperative effort not only makes possible the achievement of common goals but is in itself a product of common goals. In order to arrive at effective estimating practices for a complex operation the goals of estimating must be explicitly understood and accepted by all those who have a part in the process and procedures. It might seem that the goals of estimating are perfectly clear to anyone, but this is merely an implicit assumption, and implicit assumptions are not enough to insure cooperative team work. Explicitly stated and accepted goals do not make cooperative team work operative but they make it, at least, possible. A team of horses cannot pull together if they are each going in different directions.

Whether or not common goals can be formulated and agreed upon depends upon the subordination of individualistic or personal goals, or it requires that personal goals be fitted into the framework of the common or company goals. For an example of how the pursuit of individualistic goals can interfere with cooperative effort, let us refer again to the company already cited.

In this particular organization a paternalistic form of administration prevails. Responsibilities are delegated without being clearly defined, and authority to carry out responsibilities is rarely explicitly bestowed, so that second-level management is maintained in a dependent relationship to top management. Rivalry between department heads is encouraged on the mistaken assumption that competitiveness will stimulate productivity and increase efficiency. The result of the struggle for the position of top favor (the personal goal of department heads) is to place a premium on techniques of defense and ingratiation rather than on techniques of effective cooperative behavior within the organization. It also results in feelings of tension, pressure, and pervasive insecurity on the part of those charged with the responsibility for operating profitably. These feelings manifest themselves in the psychological mechanisms of defensiveness and projection.

Defensiveness is displayed not only in an unwillingness on the part of various department heads to accept responsibility for errors, inefficiencies, and inadequacies in their own performances and in those of their departmental subordinates, but also in an unwillingness to view objectively, with the end of improving the situation, the errors which occur, and the inefficiencies which exist in their own departmental functioning as a whole.

Projection takes the form of placing blame on other department heads for "all" the difficulties that plague a given division. This tends to obscure the real nature of the issues, and prevents analysis of the situation in such a way as to recognize difficulties as symptoms of major problems which must be objectively formulated in order to be solved.

Although this kind of defensive and projective behavior is manifest in all areas of operation, its consequences are particularly felt in the estimating practices in this company, since the department heads have as one of their functions the responsibility for estimates having to do with their areas of operation. Consequently, the estimating process becomes a competitive rather than a cooperative enterprise. This kind of competitiveness, which implies attempts to enhance the

value and importance of an individual or of a department to the disadvantage of others, results not in increased productivity but in the break-down of cooperative effort toward a common goal. Inter-individual and interdepartmental jealousies and conflicts necessarily interfere with the objective appraisal and analysis of problems. Effective planning for efficient and profitable operation, of which estimating practices are a vital part, depends upon the objective analysis of difficulties and the impersonal consideration of alternative solutions to them. Defensiveness leads to a shifting alignment of individuals who temporarily join forces to attack another or others in order to divert attention from their own real or imagined shortcomings.

Difficulties are perceived not as objects of systematic appraisal and analysis but rather as material for justifying attack against the scapegoat of the moment, or as evidence justifying ineffectual performance, depending upon whether the difficulties encountered are within one's own province or in another's area of operation. Difficulties when perceived in this manner cannot be seen as legitimate problems which must be squarely faced and dispassionately analyzed in order to be solved or dealt with by the best possible compromise.

It is commonly recognized that insecurity and pressure result in anxiety. The anxiety of a department head to enhance his prestige and the status of his own department, and pressure from other sources, may reflect themselves in estimating practices which take the form of either of two extremes. Estimates may be too low, to the end that not too large a proportion of the total cost will be charged to his department. In that case there is the danger that the company will lose money on the job. Estimates may be too high, to the end that performance will easily come within the limits set. In that case there is danger that the company will lose money on the job. Pressure from the sales department often results in the former error. Pressures from the fabricating and erection departments often result in the latter.

After engineering designs have been settled upon and the necessary information has been collected and evaluated the final step in the estimating process is a decision-making function. It is not possible to go into detail concerning the multiplicity of factors entering into this function, but I should like to draw your attention to at least one major source of error, or inaccuracy: namely, the problem of allowing for contingencies, or the safety factor problem.

The matter of the safety factor may be a fourfold problem in that allowances may be made both unconsciously and consciously but without explicit statement at both the departmental and the final, integrated cost levels. If "something" is added for safety at all four levels, the final estimates will be too high—if "something" is subtracted, they will be too low. The problem of the consciously added or subtracted, but not stated, safety factor needs only to be recognized to be dealt with. An explicit statement as to the how much has been allowed will obviate possible compounding of error.

The unconscious safety factor is a more difficult matter, and requires an understanding of personality factors in the individuals making the estimates in order to be recognized and dealt with.

You have considered with us some of the possible sources of error and inaccuracy in the process of estimating, some of the complexities and problems involved, and some of the scientific techniques which can be applied to the process in order to facilitate and improve the accuracy of procedures. It is as dangerous as it is easy to look upon practices and techniques as though they had an existence of their own, in isolation, and out of context.

I have attempted to draw your attention to the notion that techniques and practices do not carry out or apply themselves—they must be carried out or applied by some person or persons. Although this seems like a very simple and self-evident idea, it is astonishing what a complicating factor it is, and how often it is unrecognized or ignored. I hope I have been successful in pointing out some of the ways in which ignoring the human factor can prejudice the results of even the most carefully planned operations, and the most scientifically devised techniques.

Book Review

"Elements of Statistics"
by H. C. Fryer,
John Wiley & Sons, Inc.,
New York, 1954, 262 pages

The author's approach lies between the two common extremes of an over-simplified "cook book" and the exclusively theoretical treatment of the mathematician. As a result of this approach, the reader of this book can gain an introduction to statistics without excessive difficulty, but which will form an adequate foundation for understanding statistical ideas and methods. Frequency distributions, probability, the binomial and normal distributions, sampling, and correlation are covered.

INDUTRIAL ENGINEERING AT THE CROSSROADS

(Continued From Page 3)

6. STAY AWAY FROM MATHEMATICS. Industrial Engineers like to stop using mathematical analysis when they are finished with their time studies. Quantitative analysis is at the heart of Inlustrial Engineering work—so why not take full advantage of the many tools available for this type of quantification and analysis?

Industrial Engineering is a marvelous field. The future holds much for all of us—but only if we are willing, ready and able to accept the challenge offered within the field of Industrial Engineering. We must keep our eyes open. Let's not stall at the cross roads.

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A Survey

Concepts And Practices In Industrial Engineering

By Ralph E. Balyeat

Supervisor of Labor Relations Courses, Industrial Engineering Section, Purdue University

It is beyond the scope of this paper to discuss all aspects of the Industrial Engineering profession. Rather it is my intent to (1) outline problems insofar as they relate to educational requirements, (2) propose greater uniformity of basic concepts among educators, (3) discuss the results of an extensive industrial survey dealing with "Concepts and Practices in Industrial Engineering."

The departments teaching Industrial Engineering in our universities are suffering from severe growing pains. One of the evident symptoms of this malady is the variety of names we find applied: Industrial Engineering, Management Engineering, Administrative Engineering, Industrial and Management Engineering, etc. The situation is without precedent in engineering history due primarily to our rapidity of growth as a post war phenomenor. Whereas in the past we have seen the various branches of engineering segregated through a natural evolutionary process, due to the urgency of the situation the Industrial Engineering field has and must be developed to meet specific and existing requirements.

The Industrial Engineer need not become unduly concerned over the fact that several universities have adopted department titles emphasizing that Industrial Engineering training is management training. Instead, we should make this total concept of Industrial Engineering so well known and so universally accepted that such direct identification becomes unnecessary. A far greater threat to our professional status comes from those who associate our profession with specific techniques and thus perpetuate the concept that Industrial Engineering training should be limited to the study of inanimate machines and processes. The utilization of industrial engineers in industrial organizations does not bear out this restricted concept.

The course content problem is complicated still further by the fact that persons engaged in and administering industrial engineering activities in our universities have widely varying industrial and educational backgrounds and thus in turn have widely differing, "frames of reference," in considering the proper approach. Add to this factor the inherent and deeply ingrained tendency of the traditional engineer to sell himself short, plus the lack of specific knowledge as to the extent of utilization of industrial engineers in industry and the complexity of the situation begins to emerge.

The understanding and appreciation of educators outside the field has been confused and complicated by the all too frequent misuse of terms relating to specific industrial engineering techniques. In a recent article, which will be widely read by educators, the terms, "time study engineer" and "time study engineering" were repeated frequently. We also find use of terms such as, "tool engineering," "methods engineering," "planning engineering," "efficiency engineering," etc. Is it any wonder that some persons question the professional status of a group that they see referred to by these diluted terms?

One of the reasons for the diversified course content found in university curriculums lies in our failure to establish basic aims and objectives for our courses of study. It is in this respect that I stated the engineer tends to undersell himself and perhaps as a corollary we tend to undersell the products of our training. Instead of thinking in terms of techniques would it not be a more realistic objective to provide students with the necessary training to enable them to develop through work experience in order that they may use scientific principles and engineering knowledge in management positions? In his position as a member of top management he must be qualified to establish objectives and accept responsibility for designing, organizing, administering and controlling, the systems and processes necessary to utilize and integrate, the facilities and human resources of the enterprise.

It is certainly just as unrealistic to believe that every student in Industrial Engineering is a potential executive as it is to believe that all mechanical engineers will ultimately become research specialists or product development engineers. On the other hand, if we do not provide a well-rounded curriculum including more technical English, public speaking, industrial management, industrial relations, human relations, etc., we are failing to provide the pool of management potential for which industry is seeking.

In an effort to determine predominating concepts as well as utilization of Industrial Engineers, Mr. Gale Wilson*, a graduate student at Purdue University, conducted an extensive research project under the supervision of the author. 1001 questionnaires were distributed to a representative sample of manufacturers, 82 were sent to educators in the industrial engineering field and 17 were sent to management and industrial engineering consulting firms. The high degree of interest in this topic is evidenced by the fact that approximately one-third of the distributed questionnaires were returned within two weeks with many more coming in too late to be included in the statistical analysis.

When securing information from the manufacturing organizations an effort was made to determine the concepts of the executive who was the immediate superior to the Chief Industrial Engineer. It was felt that this measurement would more accurately portray the accepted role of the Industrial Engineer than would the concepts of the engineer himself.

The questionnaire was printed on a single 10" x 14" sheet, prefolded, addressed for return and stamped with return postage. It was distributed to representative companies of various sizes in each of the twenty major industry types and in each of the major geographical areas of the United States, as established by the Bureau of the Census.

The printing and publishing industry (50% return) followed closely by the machinery manufacturing industry (48.2% return) lead all groups in interest shown, as evidenced by the percentage return of questionnaires.

In answer to the question "Does Your Company Hire College Graduates Who Have 'Industrial Engineering' or 'Industrial Engineering - Option' Degrees?" we found the Rubber, Tobacco, Public Utility and Instrument Manufacturing Industries indicating 100% that they hired college graduate Industrial Engineers. Following in order came Primary Metal Products 83.3%, Furniture Manufacturing 83.3%, Transportation 80%. Lowest groups were Food Products 47.8% and Lumber Industry 42.9%. Cumulative totals show 71.7% hire graduate Industrial Engineers. Geographically speaking, the Northeastern states report the greatest hiring with 87.5% of all industries answering yes. The Western North Central States are low with 64.7%. As might be anticipated the percentage of companies hiring industrial engineers varied directly with the size of the company. The range was from companies hiring from 1-250 employees (20%) to companies over 10,000 (100%). The only significant exception was companies 5,001-10,000 (77%) which was approximately the same as reported by the 1001-1500 (75%) group.

The results of a related question asked of those companies employing graduates, "Approximately how many are now employed?" indicated some significant in-

* Wilson, Gale: "Concepts and Practices in Industrial Engineering," A Master's thesis, Purdue University, Industrial Engineering Section, 1953.

formation. Companies reporting represented a total payroll of 747,021 employees of whom 2283 were Industrial Engineers or an average of one Industrial Engineer for every 327 employees. The range of utilization when considered by type of industry varies from one Industrial Engineer per 129 employees in the chemical industry, to one for each 3,000 employees in the tobacco industry. Other industries having a relatively high utilization include, Transportation Equipment Manufacturing one per 216, Metal Fabrication one per 225, Furniture Manufacturing one per 225 and Printing Industry one per 236 employees.

Another question dealt with the relative importance of subjects frequently included in college Industrial Engineering curricula. Inasmuch as wide interest has been expressed in the answers to this question I am reporting a complete summary of answers in Table 1.

TABLE 1
SUBJECTS COMMONLY FOUND IN INDUSTRIAL ENGINEERING CURRICULUMS

Order of Importance as Reported by Educators		Order of Importance as Reported by Companies Employing Industrial Engrs.	
Rank	Subject	Rank	Subject
1	Motion and Time Study	1	Mathematics
2	Accounting	2	Plant Layout
3	Mathematics	3	Operation Analysis
4	Operation Analysis	4	Plant Operation
5	Industrial Organization & Management	5	Motion and Time Study
6	Labor Relations, Personnel	6	Production Engineering
7	Mechanics	7	Factory Planning
8	Physics	8	Wages, Job Evaluation
9	Plant Layout	9	Production Planning
10	Factory Planning	10	Mechanics
11	Production Planning	11	Production Control
12	Mechanical Drawing	12	Mechanical Drawing
13	Technical Writing	13	Labor Relations, Personnel
14	Strength of Materials	14	Industrial Organization & Management
15	Engineering Materials	15	Human Engineering
16	Production Control	16	Industrial Reports
17	Engineering Economy	17	Quality Control
18	Statistics	18	Surveys and Reports
19	Technical English	19	Engineering Economy
20	Economics	20	Industrial Economics
21	Production Engineering	21	Physics
22	Electrical Engineering	22	Statistics
23	Plant Operation	23	Safety Engineering
24	Wages, Job Evaluation	24	Technical Writing
25	Quality Control	25	Technical English
26	Industrial Economics	26	Accounting
27	Tool Engineering	27	Mechanisms
28	Business Law	28	Machine Design
29	Thermodynamics	29	Economics
30	Machine Design	30	Tool Engineering
31	Human Engineering	31	Engineering Materials
32	Safety Engineering	32	Electrical Engineering
33	Mechanisms	33	Strength of Materials
34	Chemistry	34	Chemistry
35	Metallurgy	35	Finance
36	Surveys and Reports	36	Metallurgy
37	Fluid Mechanics	37	Fluid Mechanics
38	Industrial Reports	38	Business Law
39	Finance	39	Thermodynamics
40	Government and Political Science	40	Government and Political Science
41	Surveying	41	Surveying

A comparison of the rankings of industry with those of educators show extensive and important differences in practically every subject. Nine subjects differed in rank 15-24 places with educators ranking accounting, strength of materials and engineering materials *higher* and industrial reports, plant operation, surveys and reports, wages-job evaluation, human engineering and production engineering *lower*, than did the industries reporting. Although some of these differences are no doubt due to differing concepts of course content yet it is apparent that there is a definite need for a more unified understanding and concept of the basic functions of Industrial Engineering by both groups. It is also significant to note that of the 18 additional courses suggested by from 1-6 companies, only two dealt with engineering techniques, with the remainder involving typical non-technical subjects including Public Speaking, English, Composition, Psychology, Logic, etc. These suggested courses clearly imply a desire for greater emphasis on those related courses preparing the student for later managerial appointments.

When considering the answers to the question, "Does your company's organization specifically include an Industrial Engineering Department?" in order to make the results more meaningful, companies answering yes were combined with those stating they had departments set up to perform clearly established Industrial Engineering functions, though these departments were not so named. Examples cited are, "Standards Departments," "Incentive Department," "Methods Department," etc. Considerable variation was found among different industries. Leaders were the Rubber Industry with 75%, Textile Industry 64.2%, and Electrical Machinery Manufacturing with 59.1% reporting such departments as compared to Lumber Industry 12.5%, Public Utilities 16.7%, and Paper Industry 30%. The average of all industries was 45.2%.

Differences by geographical area no doubt reflect largely the predominating type of industry located in these areas. In the Northeastern area for example, only 33% reported Industrial Engineering Departments with the Western South Central district reporting 60%, and Eastern North Central 48.2%.

It was rather surprising that no significant correlation was found between the size of companies (above 750) and the existence of an Industrial Engineering Department. For example, companies by size reported as follows: 751-1000—55.6%, 1001-1500—52.6%, 2001-3000—45.8%, and over 10,000—58.6%. These differences may largely be due to sampling.

The titles applied to the Head of the Industrial Engineering Department were relatively few in number with 40% using the title "Chief Industrial Engineer," 22%—"Industrial Engineer," and 24%—"Industrial Engineering Department: Head, Manager, Director, or Supervisor."

The relatively high executive position of the Chief Industrial Engineer in most companies is evidenced by the fact that 37% report to a Vice President, 8% directly to the President, and 46% to Plant, Works, Division or Factory: Manager, Division Manager, General Manager, Superintendent, or General Superintendent.

This position was also indicated by 64.7% of all companies reporting that they considered the Chief Industrial Engineer a member of Top Management, with 100% of several industries reporting that they considered this to be true.

One question asked the respondent to indicate who they thought should be responsible for the cooperation and utili-

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zation of men, materials and machines to achieve the most economical production. As might be anticipated many opinions were expressed on this point and several letters were received elaborating on the respective concepts. Of greatest significance, however, is the degree of acceptance of the Chief Industrial Engineer in this capacity by those companies having Industrial Engineering Departments, with his relatively low degree of acceptance by those companies not having such departments. In companies having Industrial Engineering Departments, where other titles were mentioned, very often statements were made that coordination and utilization should be a joint responsibility of the Chief Industrial Engineer and the executive mentioned. Most common combinations were Vice Present or Plant, Works, or Division Manager in cooperation with the Chief Industrial Engineer. Significant also, was the number of companies not having an Industrial Engineering Department that indicated the desirability of having an Industrial Engineer in this capacity.

In respect to the utilization of Industrial Engineering Consultants, it was somewhat surprising to learn that companies having Industrial Engineering Departments still utilized consultant Industrial Engineers more than did companies not having this department. The composite summary for all industries indicate 76.6% of all companies having Industrial Engineering Departments utilize Industrial Engineering Consultants with only 65.8% of the companies without Industrial Engineering Departments utilizing this source of assistance. Also, it is apparent that more information should be provided for the small industrialist, outlined advantages of utilizing consultants for special problems, inasmuch as 38% of companies with under 750 employees indicate that they never utilize the services of consulting engineers.

One section of the questionnaire dealt with various plant functions and the question was asked, "In your opinion is either Design or Administration an Industrial Engineering function." When considering the results of this summary, the tendency of the responder to indicate practice in his specific company rather than opinion must be recognized. In fact, many accompanying letters stated plans for revising practices to conform more closely with the concepts of present administration. The summarized answers appear in Table 2. Pursual of these figures reveals, in all instances (excepting maintenance activity), educators more prone to associate the design phase of various functions with Industrial Engineering than are industrial organizations. This does not hold true in administrative activities, as in 10 instances a higher percentage of companies accepted administration as an Industrial Engineering function than did the educators and, in one instance, Personnel Policies and Procedures, this percentage was nearly doubled on the part of companies replying.

It appears from this study that our greatest immediate need is a better understanding and concept of optimum objectives for Industrial Engineering courses. Industrial Engineering professors should adapt the "horizons unlimited," concept by recognizing the potentialities of the existing need for engineers. Engineers, not only technically competent, but who are also articulate both verbally and in writing and who have the ability to form opinions and make decisions rationally, logically and objectively. Our greatest weakness appears to be in our communications. On the part of educators this results in failure to disseminate information relative to new courses, new applications, new methods and the potentiality of their product, the Industrial Engineering graduate.

TABLE 2
CONCEPTS OF INDUSTRIAL ENGINEERING FUNCTIONS

The survey questionnaire presented a list of functions frequently associated with Industrial Engineering, and suggested that they could be thought of as consisting of two phases of activity:

DESIGN—The study, planning and development of the methods, procedures or systems required to control the performance of the function.

ADMINISTRATION—The actual performance or control of the function utilizing the designed methods, procedures or systems.

The respondents were asked to indicate whether or not they regarded these functions as Industrial Engineering functions. The percentages listed represent affirmative answers and are based on total response indicated in column headings.

Function	Companies		Consultants		Educators	
	Design	Admin.	Design	Admin.	Design	Admin.
	%	%	%	%	%	%
Prod. Plan & Scheduling	63.3	36.6	71.4	28.6	86.2	48.3
Production Control	52.3	36.2	85.7	28.6	79.3	51.7
Material Control	45.1	30.6	7.14	14.3	69.0	41.4
Inventory Control	37.9	24.2	57.1	14.3	55.2	34.5
Quality Control	40.9	31.9	57.1		72.4	55.2
Office & Plant Layout	82.5	50.2	85.7	57.1	96.6	51.7
Design of Equip. of Fac.	64.2	33.6	71.4	14.3	58.6	20.7
Tool Engr., Jigs & Fix	52.7	31.1	85.7	14.3	79.3	48.3
Maintenance — Mach. & Equip.	34.0	21.7	28.6	14.3	27.6	24.1
Maintenance — Build & Facil.	30.2	21.3	28.6	14.3	17.2	17.2
Safety Programs	34.0	29.4	28.6	14.3	58.6	44.8
Waste Elim. & Salvage	59.1	40.4	85.7	14.3	72.4	51.7
Office Management & Proc.	34.5	18.7	85.7	14.3	55.2	27.6
Process Engineering	66.8	43.4	100.0	57.1	62.1	58.6
Methods Analysis & Stand.	87.2	66.8	100.0	71.4	96.6	69.0
Personnel Policies & Proc.	23.4	19.6	14.3	14.3	31.0	10.3
Training Programs — Super.	34.4	30.2	42.9	42.9	41.4	31.0
Training Programs — Prod. Worker	34.4	27.7	57.1	28.6	44.8	31.0
Labor Rel. — Griev. Settle.	21.3	20.4	14.3	14.3	27.6	17.2
Job Evaluation	68.1	58.3	71.4	71.4	86.2	58.6
Merit Rating	38.3	33.2	42.9	42.9	58.6	31.0
Time Study	83.4	75.3	100.0	85.7	89.7	69.0
Rate Setting	75.7	68.1	85.7	100.0	86.2	62.1
Wage Incentive Systems	73.2	65.9	85.7	85.7	82.8	55.2
Cost Est. — Production	65.5	54.9	85.7	85.7	79.3	31.0
Cost Records & Control	33.2	26.8	28.6	14.3	65.5	34.5
Special Projects	51.1	39.1	71.4	14.3	44.8	24.1

THE PRESIDENT SPEAKS

(Continued From Page 2)

tear down the standing of the engineering profession in general.

This brings us to my third topic of professional engineering registration. I, personally, am thoroughly convinced that the time has now come for professional registration of all qualified engineers. Any engineer worthy of the name should be willing to stand up and be counted. There are too many situations where various pressures, including political and economic, allow one man to certify for non-engineers or unqualified men claiming to be engineers. Situations where the glitter of too many available jobs influence even normally ethical and recognized leaders to put on more unregistered "engineers" than is possible for them to check on, resulting in taking a chance and blindly approving unsound engineering practices. A situation where graduates of a school turned down by E.C.P.D. or other qualified accrediting agencies (if any) can claim to be a qualified engineer is, in my opinion, completely "out of control" as far as "quality" is concerned.

This problem is a tough one. There are still a few State Registration Boards with too many "grandfather" and "mightier than thou" members. Space will not permit further discussion in this direction but the time has come for joint effort by all professional societies to work for the profession as a whole and not for a chosen few or by a chosen few. State and/or National Professional Registration seems to be the answer. Maybe membership (not affiliates) in the professional engineering societies would do it, if so who will "police" the societies to see that their membership requirements are sound? Maybe recognition of professional ability should require registration in at least one State and concurrent membership in at least one professional society to indicate the general field of qualifications.

I have enjoyed the honor and privilege of being your National President for the past year. I have also enjoyed the pleasant as well as the less pleasant problems that have arisen.

May I see you in Louisville?

I will . . . if you will.

PLANT INVESTMENT SURVEY

(Continued From Page 8)

was evaluated by several distinct management levels and with considerable time delay, before it received its final disposal. Customarily an economy study was given a more or less formal written presentation in the engineering department; hence it was at this level that pertinent cost and income data, as well as an interest rate if it were used, were combined by the use of one of the common methods into a criterion of a proposed investment's merits. The final decision on all but very small investments however, was made by either the president or the board of directors of the firm. As a result, direct communication between the people responsible for deriving the investment criterion and the people rendering the final decision was seldom evident. Moreover there was usually a substantial time lag between the completion of the economy study calculations and the final action on the study. This was quite often the case because for budgetary purposes, most capital expenditures had to be submitted for consideration long before money could be allocated to them.

The survey also revealed that the persons who were responsible for making the final investment decision will, in most instances, temper the indication of the written economy study criterion with their own appraisal of the intangibles associated with a particular investment. The persons who conducted the actual cost study, either because they were familiar with this procedure or because they wished to ignore intangibles, usually did not attempt to compensate the investment criterion for risk, uncertainty, or other intangible qualities. However, a constant, blanket adjustment for over-optimistic cost estimates was often applied to all investments indiscriminately.

There was substantial evidence that many of the persons who conducted the economy studies were unfamiliar with both the concept of discounting a future sum of money to find its present value and with the considerations usually associated with the cost of capital. In fact the cost of capital was usually assumed to be the same as the current yield on government savings bonds or bank savings deposits. In no case was there any indication that they considered that the cost of capital would be largely dependent on the means chosen by top management to obtain this capital.

Theoretical Considerations. A comprehensive investigation of the literature, which time does not permit us to go into with detail, indicated that the rate of return criterion could be determined by two distinct methods. One method, called the Diminishing Capital Investment method, was ostensibly based on the discount interest rate since it was essentially a present worth calculation. This method of calculating an investment criterion allowed but one well defined interest rate to be used. This interest rate was the rate of return on the particular investment in question. The other method, the Constant Capital Investment method, was apparently based on the earnings interest rate since it required an accumulation of interest bearing funds or sinking fund. The interest rate for this method however, was not well defined and could apparently be based on numerous factors. Nevertheless, the weight of authoritative opinion indicated that there were five prominent factors which should influence the choice of this interest rate. These factors were: 1. the cost of capital; 2. the earning power of money; 3. the associated risk and uncertainty; 4. the conservative bias; and 5. a possible compromise using two interest rates. Of these five factors all but the earning power of money or long-run future earnings rate proved to be unworthy of further consideration in selecting the Constant Capital Investment interest rate since they had many shortcomings.

Theory and Practice Combined. The shortcomings of these factors were revealed through the industrial survey and were primarily manifestations of the practical restrictions created by the division of authority with which most firms handled their proposed investments. This division of authority, as previously mentioned, was the procedure wherein the engineering department derived the investment criterion, but the top executives of the firm reserved the right to make the final investment decision, to temper the investment criterion for risk and uncertainty, and to choose the method of financing accepted projects. As a result of this analysis and elimination, the two most acceptable interest rates for either method were found to be the long-run future average earnings rate of a firm's future capital investments and the rate of return on the individual investment in question.

The effectiveness of these two rates of interest was compared by comparing the Constant Capital Investment method and the Diminishing Capital Investment method of calculating a return on the investment. This was possible since when the rate of return on the individual investment is used as the Constant Capital Investment interest rate this method became identical with the Diminishing Capital Investment calculation. Hence comparing one method with the other was the same as comparing the two interest rates. The comparison of these two methods or interest rates was thereby carried out within a framework of capital budgeting with the use of capital supply and demand curves. The results of this comparison indicated that the Diminishing Capital Method or the *rate* of return on the individual investment was the more preferable of the two rates or methods.

Conclusions. As a result of the interest rate study (4) the following conclusions seemed to be justified and to satisfy the original purposes. 1. The abstract quality of the discount interest rate and the earnings interest rate required their identification with some method of calculating an investment criterion and since, for a firm which is in business to make profits, the only suitable investment criterion is the rate of return on the invested capital, the salient consideration is that interest rate which best suits a rate of return calculation. 2. Within the typical manufacturing company of Alameda county the time value of money was not considered to be of sufficient importance to merit the use of an interest rate in an engineering economy study. But, if an interest rate were considered to be necessary, the typical value used would be a low rate, very near the current rate on savings bonds. 3. There are but two interest rates for use in engineering economy study calculations of a rate of return which have a solid foundation in economic theory, are accompanied by complete and logical rationalizations for their use, and do not possess impractical features which would conflict with the customary division of authority found in the typical business firms' procedures for handling proposed investments. These two rates are the long-run future average earnings rate on future capital investments and the rate of return on the individual investment under consideration. However, between these two interest rates the rate of return on the individual investment may be considered the more elegant. This is so since it is not only self-determinant, but by its very nature it will act as an automatic predictor of the long-run future average earnings rate and thereby satisfy the theoretical conditions of both interest rates.

SUMMARY

1. The *growing* importance of the "best way" in engineering investment analysis is pointed up, especially by the trend toward greater emphasis on capital costs in relation to total costs.
2. The importance of closing the gap between known theory and its practice in the field is seen in the costly errors revealed by the survey. The use of inadequate formulas, improper use of adequate ones, and lack of facts on real costs, economic lives, and interest rates are examples. Last but often not least is the importance of really integrated chains of information and command.
3. When more information is available on actual practices and the reasons for them, our theory presentations will be stronger and more intelligible. For example—how do some decision-makers really decide—how is the capital supply curve defined? In plain English, "Where do we get the money for proposed investment and what is the cost of it?"

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WORK SAMPLING APPLICATIONS

(Continued From Page 6)

above. Another device, applied to small crews in the California packing house studies, is to obtain simultaneous observations on each crew member, with each set of observations obtained at a predetermined interval. In studies of small crews, this interval may be short, say 0.2 minute. This device serves the purpose of momentarily diverting the observer's attention from the work crew after each round. It also is a means of preventing a disproportionate accumulation of delay observations during periods when the entire crew is delayed and the recording of observations is less timeconsuming than when the usual distribution of observations to several categories is required. We have called this process "continuous work sampling." It should be noted that continuous work sampling assumes that the events observed do not occur cyclically or systematically but are random occurrences. If this assumption is not appropriate, some means of randomizing the observations would be required, or, more simply, assurance that the work cycle and observation cycle are not synchronized would be necessary.

Considerations in Choice of Study Method

Experience with the work-sampling technique indicates that it has a relatively broad field of application and that, under suitable circumstances, it is an alternative to time or production study methods. The choice of method for a particular study involves several considerations.

A frequently claimed advantage of the work-sampling method is lower cost. Some reports on this method indicate costs in the neighborhood of one-quarter to one-half the cost of time and production studies (3) (7). While such economies are possible, the relative costs in a particular case will depend on the work situation under study and the kind of measurement desired. The situation most favorable to work sampling is one involving several workers performing the same job and in which a representative measure for the entire group is desired rather than performance data on individual workers. In this situation, observations on the entire group can be pooled and the number of observations required for a desired level of reliability can be obtained in a relatively short period. Work sampling may also be economical in situations involving individual workers on different jobs, if a number of such jobs can be sampled successively and quickly, with the result that work measurement data on several jobs are obtained concurrently.

When several different jobs are covered in a single work-sampling study, the study time per job frequently will be substantially less than with time study or production study methods. The total length of the observation period may, however, be much longer. This should result in more complete information on delays. Moreover, there should be less bias due to worker reaction to the study, as the maintenance of an abnormal pace over the longer period of observation is less likely than with the relatively short-period time or production studies. In addition, worker reaction probably is reduced by the intermittent and instantaneous nature of the work-sampling observations.

Work-sampling procedures appear less well adapted than time or production studies to the measurement of variation between individual workers. If "rating" or "leveling" is desired, the mechanics of this procedure are simpler with time or production studies. For some observers, the large number of (and frequently repeated) ratings required to "level" work-sampling observations may create difficulty in maintaining consistency in successive ratings.

In studies of crew operations, quantification of interactions between members of the work crew by means of time or production studies is difficult. Such interactions can be measured easily by work-sampling procedures.

Statistical tests of reliability can be readily established. This is beneficial from the standpoint of work measurement and may aid in labor-management relations.

Summary

Work sampling, a system based on random, instantaneous observations, is being applied to a growing range of work measurement problems. These include the estimation of equipment and operator utilization percentages, work simplification analyses, the determination of element and production unit time requirements, studies of the flow pattern in materials handling, studies of jobs involving team methods of operation, and numerous other applications.

In many situations, work measurement data can be obtained more economically by work sampling than with production or time studies, and the data are frequently more representative and more complete. The interactions between different stages of plant operation, or between different members of a work crew, often can be studied more effectively by work sampling than by other means.

Ideally, the procedures used in obtaining work-sampling observations should be designed to provide random, independent observations. While these conditions may not be fully met in all situations, they can be approximated closely enough to provide unbiased estimates and to permit the application of statistical criteria of reliability to the observed proportions.

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